WHITE PAPER NO. 6B – *IN-SITU* CAPPING AS A REMEDY COMPONENT FOR THE LOWER FOX RIVER

Response to a Document by The Johnson Company

ECOSYSTEM-BASED REHABILITATION PLAN – AN INTEGRATED PLAN FOR HABITAT ENHANCEMENT AND EXPEDITED EXPOSURE REDUCTION IN THE LOWER FOX RIVER AND GREEN BAY

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ABSTRACT

This White Paper is the second in the series in which the Wisconsin Department of Natural Resources (WDNR) and United States Environmental Protection Agency (EPA), through Dr. Michael Palermo, address the capping alternative remedy proposed by the Appleton Paper, Inc. Panel's (API Panel's) report entitled *Ecosystem-Based Rehabilitation Plan – An Integrated Plan for Habitat Enhancement and Expedited Exposure Reduction in the Lower Fox River and Green Bay* (referred to herein as the "Panel Report") (The Johnson Company, 2002), and the multiple comments received during the comment period on capping as a remedial alterative. While WDNR and EPA did not include *in-situ* capping (ISC) as part of the *Proposed Remedial Action Plan, Lower Fox River and Green Bay* (Proposed Plan) (WDNR and EPA, 2001), they had, and continue to acknowledge that ISCs are feasible, implementable, and effective. WDNR and EPA have concluded that while capping could be considered a component of the final remedial alternative for the Lower Fox River, it cannot be the sole remedial action on the Lower Fox River, and it would not eliminate the need for removal actions in order to meet the defined goals within the Proposed Plan.

This White Paper examines ISC as a remedy for the Lower Fox River. In light of the Panel Report, it was necessary for WDNR and EPA to articulate site-specific design criteria for the Lower Fox River consistent with national guidelines, national and international experience at constructing and monitoring ISCs, and local, Wisconsin state, and federal requirements. To that end, this White Paper articulates the minimal engineering design evaluations needed including modeling to assess consolidation, the potential for advective and diffusive flux from either consolidation or from groundwater intrusion, and evaluation of local capping material and iterative design testing to ensure that cap design is effective in chemical isolation.

This White Paper elucidates the technical considerations for potential capping areas, including that the overall remedy must manage all sediments within the 1 part per million (ppm) contour, and should achieve a sediment-weighted average concentration (SWAC) of 250 parts per billion (ppb); that no capping would occur in designated navigation channels in areas of infrastructure such as pipelines, utility easements, bridge piers, etc. (with appropriate buffer) in areas with polychlorinated biphenyl (PCB) concentrations exceeding Toxic Substances Control Act (TSCA) levels, in shallow-water areas because of habitat and ice scour considerations without prior deepening to allow for cap placement.

This White Paper further sets forth key design elements for any potential capping remedy including physical isolation of the PCB-contaminated sediments from benthic organisms; physically stability from any scour event; isolation of the PCB-contaminated sediments in perpetuity from flux or resuspension into the overlying surface waters based upon a performance criteria for chemical isolation of 250 ppb of PCBs in the cap sediment in the biologically active zone. Further, the cap design will consider operational factors such as the potential for cap and sediment mixing during cap placement and variability in the placed cap thickness, and it will incorporate an appropriate factor of safety to account for uncertainty in site conditions, sediment properties, and migration processes. Finally, institutional/regulatory constraints associated with capping, such as capping TSCA materials, lake bed grants, riparian owner issues, deed restrictions, fiduciary responsibility, and long-term liability should be fully considered in selecting potential areas for and design of any cap.

1 INTRODUCTION

1.1 BACKGROUND

Sediments in the Lower Fox River are contaminated with PCBs. Remedial alternatives for the Site are currently being evaluated by the WDNR and EPA. This White Paper describes considerations for further evaluation of an ISC as an alternative for the project.

ISC was identified within the *Feasibility Study for the Lower Fox River and Green Bay, Wisconsin* (FS) (RETEC, 2002a) as an appropriate and applicable remedy for consideration within the Lower Fox River and Green Bay. Illustrative designs for ISCs were described in the FS and incorporated into alternatives evaluated for each Operable Unit (OU) of the River based upon site-specific physical considerations. *In-situ* caps were then further evaluated using the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) criteria related to short- and long-term effectiveness, implementability, reduction in toxicity, mobility, volume through treatment, and cost.

The WDNR and the EPA did not include ISCs as part of the Proposed Plan. While acknowledging that ISCs are effective, feasible, implementable, and are effective in the short-term, long-term concerns over maintenance of the current hydraulic controls (i.e., dams, water depth, and navigation channels) and costs/responsibilities associated with operations and maintenance of a cap in perpetuity were reasons cited for not including capping as part of the Proposed Plan. While capping could be considered a component of the final remedial alternative for the Lower Fox River, it cannot be the sole remedial action. Capping does not eliminate the need for removal actions in order to meet the defined goals within the Proposed Plan.

Multiple comments were received from public and private entities on capping alternatives for the Lower Fox River; both supporting and opposing any capping within the River. Opponents of capping focused on the commitments needed to maintain long-term cap integrity and provide for public safety, while cap proponents criticized the WDNR for failing to include a capping alternative in the Proposed Plan. One of the Potentially Responsible Parties (PRPs) for the Lower Fox River, Appleton Papers Inc., assembled a panel (API Panel) of university professors and researchers to evaluate the removal and capping alternatives proposed for the Lower Fox River. The API Panel critiqued the site-specific criteria articulated in the FS, and produced an alternative plan (the Panel Report) for capping major portions of the Lower Fox River (The Johnson Company, 2002).

In light of the Panel Report, it was necessary to articulate site-specific design criteria for the Lower Fox River consistent with national guidelines, national and international experience at constructing and monitoring ISCs, and local, Wisconsin state, and federal requirements.

1.2 Purpose and Scope

The goal of this paper is to provide specific guidance on how a capping alternative should be designed, evaluated, and managed to include long-term requirements for monitoring and institutional controls for the Lower Fox River. It is intended to address concerns raised regarding long-term protection from contaminants, long-term liability, and operations and maintenance.

This paper describes the technical, regulatory, and institutional considerations for selecting and designing subaqueous ISC as a remedy component for the Lower Fox River. General technical considerations for ISC design are summarized and specifics on application of existing cap design guidance for the Lower Fox River are described. This White Paper follows the ISC chapter in EPA's recent release *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA, 2002). This paper also considers Wisconsin and federal laws as they may impact final selection and design of an ISC alternative.

1.3 Capping as a Remedial Alternative

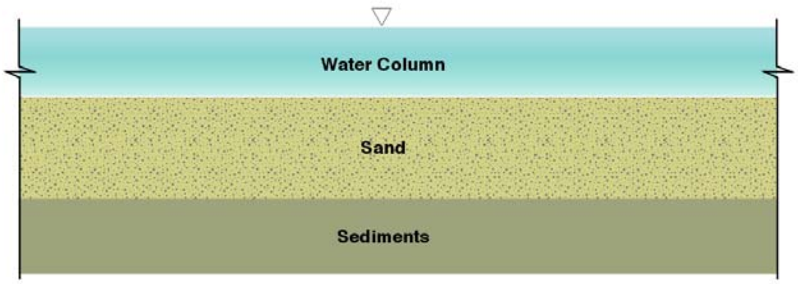
1.3.1 Definitions

For the purposes of evaluating capping within the Lower Fox River, the following definitions are applicable.

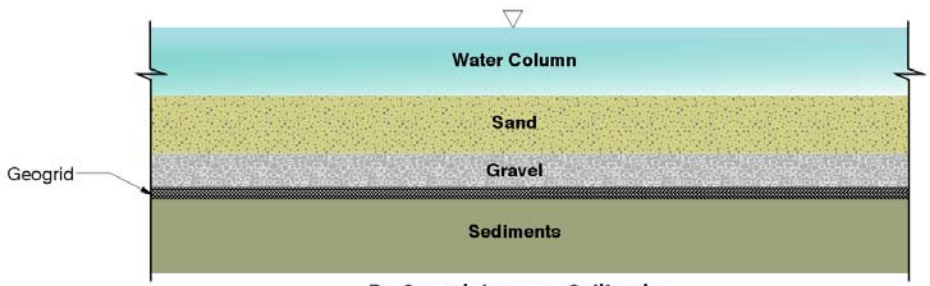
***In-Situ* Capping** is defined as the placement of an engineered subaqueous cover, or cap, of clean isolating material over an *in-situ* deposit of contaminated sediment. Capping of subaqueous contaminated sediments is an accepted engineering option for managing dredged materials and for *in-situ* remediation of contaminated sediments (EPA, 1994, 2002; NRC, 1997, 2001; Palermo et al., 1998a, 1998b). *In-situ* caps are generally constructed using granular material, such as clean sediment, sand, or gravel, but cap designs can include geotextiles, liners, and multiple layers. Such engineered caps are also called isolation caps. Figure 1 illustrates several example isolation cap designs. *In-situ* capping may be considered as a sole remedial alternative or may be used in combination with other remedial alternatives (e.g., removal and monitored natural recovery). For example, areas of higher contamination can be dredged and areas with a lower level of contamination can be capped.

***In-situ* Capping with Partial Removal** is an option involving placement of an ISC over contaminated sediments which remain in place upon completion of a partial dredging action. In this case, ISC involves the removal of contaminated sediment to some depth followed by ISC of the remaining sediment. This can be suitable where capping alone is not feasible due to habitat, hydraulic, navigation, or other restrictions on minimum water depth. *In-situ* capping with partial dredging can also be used when leaving deeper contaminated sediment capped in place is desirable for preserving bank or shoreline stability. When ISC is used with partial dredging, the cap is designed as an engineered isolation cap, since a portion of the contaminated sediment deposit is not dredged and remains in place.

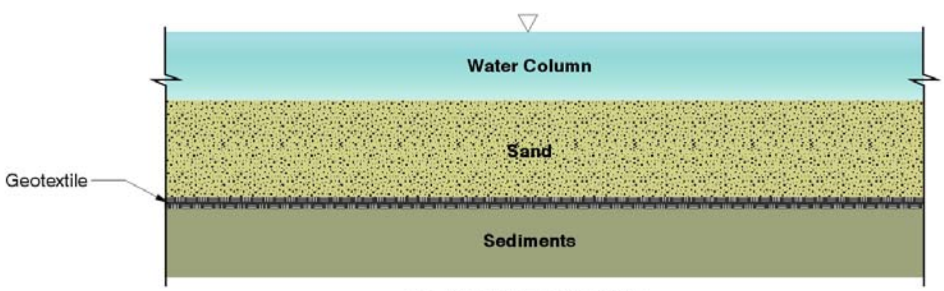
FIGURE 1 EXAMPLES OF CAP DESIGNS



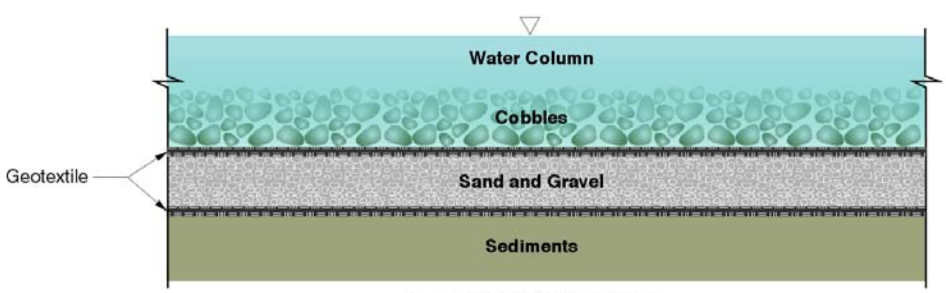
A. Eagle Harbor, Washington
(EPA/USACE 1995)



B. Convair Lagoon, California
(Mehr and Sanders, 1996)



C. Mocks Pond, Indiana
(RETEC, 2001)



D. Sheboygan, Wisconsin
(Palermo et al, 1998)

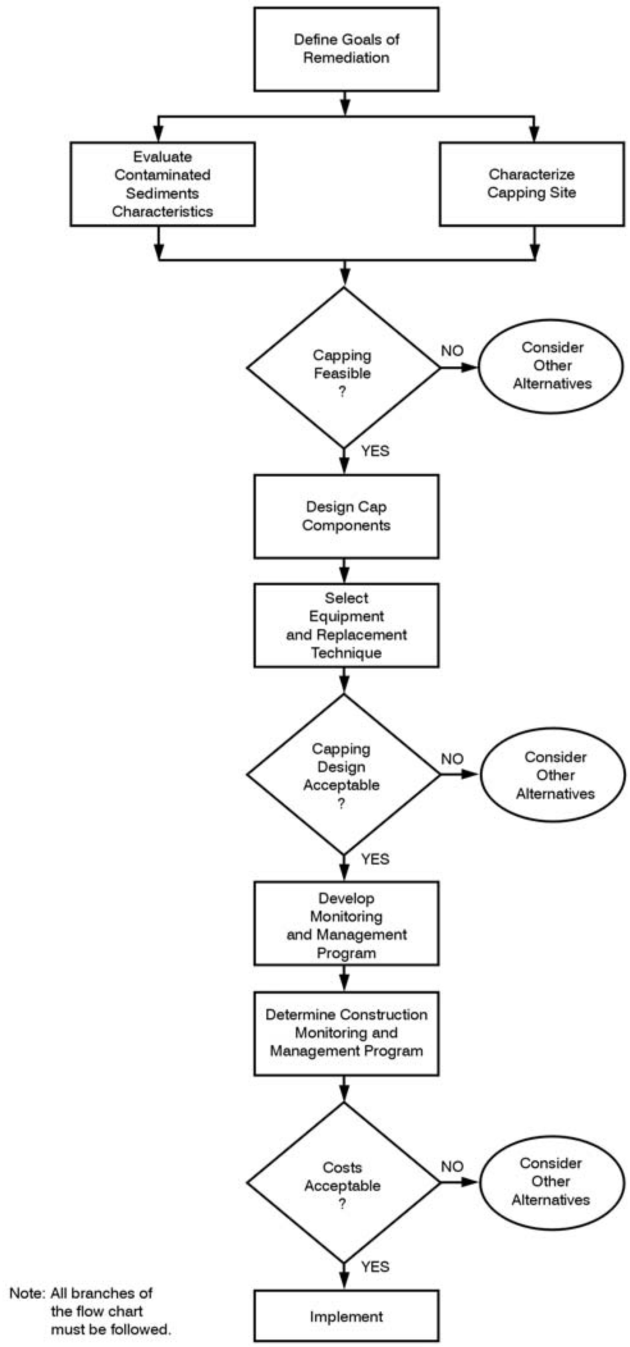
Residual Capping is defined as placement of a thin cap layer over a thin layer of residual sediment left behind following dredging. In this case, the dredging operation is designed to remove all the contaminated sediments, but the dredging process resuspends contaminated sediment that resettles onto the dredged surface, forming the residual layer. Such residual layers are typically a few centimeters thick. Residual capping serves to dilute this thin layer of contaminated sediment and speed up the natural recovery process. Residual caps are not designed as isolation caps. An example of a residual cap is the material placed at the Sediment Management Unit (SMU) 56/57 demonstration project.

Residual capping may be employed in OUs of the Lower Fox River as a means to manage residual sediments following completion of removal. *In-situ* capping (isolation capping) may be employed as a remedy component in areas not dredged, or in areas with minimal removal. This paper focuses primarily on considerations for isolation capping as a remedy component.

1.3.2 Capping Guidance Documents

Detailed guidance for subaqueous dredged material capping and ISC for sediment remediation has been developed by the U.S. Army Corps of Engineers (USACE) and EPA. The documents *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA, 2002), *Guidance for Subaqueous Dredged Material Capping* (Palermo et al., 1998a), and *Guidance for In-Situ Subaqueous Capping of Contaminated Sediments* (Palermo et al., 1998b), provide detailed procedures for site and sediment characterization, cap design, cap placement operations, and monitoring for subaqueous capping. These guidance documents serve as the technical basis for this White Paper and should be consulted for a more detailed discussion of the various topics. Figure 2 illustrates in flowchart format the major steps in evaluating and implementing an ISC remedy.

FIGURE 2 DESIGN SEQUENCE FOR *IN-SITU* CAPPING PROJECTS



In addition to these documents, there are multiple references that discuss physical considerations, design, and monitoring requirements for capping. These include the following:

- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett et al., 1990);
- *Design Requirements for Capping* (Palermo, 1991a);
- *Site Selection Considerations for Capping* (Palermo, 1991b);
- *Washington State Department of Ecology 1990 Standards for Confined Disposal of Contaminated Sediments Development Document* (Ecology, 1990);
- *Equipment and Placement Techniques for Capping* (Palermo, 1991c);
- *Monitoring Considerations for Capping* (Palermo et al., 1992);
- *Subaqueous Capping of Contaminated Sediments: Annotated Bibliography* (Zeman, et al., 1992); and
- *Design Considerations for Capping/Armoring of Contaminated Sediments In-Place* (Maynord and Oswalt, 1993).

The salient elements of site selection, design, construction, monitoring, and liability management from these references will be discussed in this paper. However, any proposed capping program should include a detailed consideration of those elements from the individually cited papers.

1.3.3 Advantages and Applicability of an ISC Alternative

A principle advantage of ISC is that contaminated sediments are isolated by the cap in-place and do not require removal. Because the capping operation covers the contaminated sediment, the potential for contaminant resuspension and the risks associated with dispersion of contaminated materials during construction is relatively low and comparable to environmental removal operations. Also, a major advantage is that no disposal site or *ex-situ* treatment for the dredged sediment is needed. Most capping projects use conventional and locally available materials, equipment, and expertise. For this reason, in certain cases the ISC option may be implemented more quickly and may be less expensive than options involving removal and disposal or treatment. Depending on the location of the cap, the type of construction, and the availability of materials, a cap may be readily repaired, if necessary.

A well-designed, properly constructed and placed on the contaminated surface, cap along with effective long-term monitoring and maintenance, can prevent bioaccumulation by providing long-term isolation of bottom-dwelling organisms from the contaminated sediments, and the prevention of contaminant flux into the surface water. Incorporation of habitat elements into the cap design can provide an improvement or restoration of the biological community.

The National Research Council (NRC, 1997) provided general guidance on where conditions would be favorable, or not favorable, for the consideration of ISC. Table 1 summarizes conditions favorable for capping (NRC, 1997) and corresponding conditions for the Lower Fox River.

TABLE 1 SITE CONDITIONS THAT FAVOR ISCS AND THE CORRESPONDING CONDITIONS ON THE LOWER FOX RIVER

Conditions Favorable for ISC (NRC, 1997)	Corresponding Conditions for the Lower Fox River
Contaminant sources have been sufficiently abated to prevent re-contamination of the cap.	Sediments are considered the major source of PCBs in the Lower Fox River. External sources of PCB inflow have been controlled. The potential for recontamination is low if capping is implemented as part of an overall remedial program and in a downstream sequence.
Contaminants are of moderate to low toxicity and mobility.	Only non-Toxic Substances Control Act (TSCA) areas will be considered for capping (see discussion below).
Monitored natural recovery (MNR) is too slow to meet RAOs in a reasonable time frame.	MNR may be appropriate for OUs 2 and 5, but is considered non-protective for OUs 1, 3, and 4.
Cost and/or environmental effects of removal are very high.	Construction costs of a complete removal of all PCBs to levels below sediment quality thresholds are high.
Suitable types and quantities of cap materials are available.	Capping materials are available within the general area of the Lower Fox River.
Hydrologic conditions will not compromise the cap.	The Lower Fox River is a hydraulically controlled River but still has potential for scour during flood events. Ice accumulations during winter could compromise cap integrity. Armor layers will be a required cap component. Selection of an ISC must consider dam maintenance as part of long-term institutional controls.
Weight of the cap can be supported by the original bed.	Capping has been successful at sites with physical sediment properties similar to conditions on the Lower Fox River.
Cap is compatible with current and/or future waterway uses.	Some areas within the OUs are incompatible with a capping remedy. Capping would be applied as a remedy component in combination with removal.
Site conditions are not favorable for complete removal of contaminated sediment.	Site conditions do not limit the applicability of a removal alternative.

1.3.4 Disadvantages, Uncertainties, and Limitations of an ISC Alternative

A principal disadvantage of ISC is that contaminated sediment will be left in place and not removed from the River. Since ISC leaves the contamination source in place, the sediment is not treated or detoxified. It is often necessary to rely on institutional controls, which can be limited in terms of effectiveness and reliability, to protect the cap. Although the isolation and containment associated with capping can be effective for hundreds of years or longer, contaminants will slowly migrate from the deposit over time. Long-term cap performance monitoring and maintenance is therefore required, which can offset part of the capital cost savings over removal. Capping sites within the Lower Fox River may be subject to catastrophic events, such as major floods, ice scour, and dam removal or failure. These events have the potential to erode or undermine the cap, and should be factored into remedy selection, design, and monitoring.

To provide erosion protection, it may be necessary to use cap materials that are incompatible with native bottom materials and can alter the biological community. Depending on the site and cap design, it may be desirable to select capping materials that discourage colonization by native deep-burrowing organisms to limit bioturbation. In either case, the cap may be relatively poor habitat for the local biological community.

For sediments with high organic content, significant gas generation will occur due to anaerobic degradation. The influence of this process on cap effectiveness presents an uncertainty that is difficult to account for in modeling cap processes.

Some of the most important factors that should be present at a site to conclude that capping may be a feasible and appropriate remedy, include the ability of the *in-situ* contaminated sediment layer to support a man-made or naturally deposited cap, and the compatibility of capped deposit with waterway use.

In addition, institutional controls necessary to protect the cap, such as restrictions on fishing or anchoring, may not be reliable, and therefore may not be an effective means of enforcement. The cost of routine cap maintenance and repair should be included in the cost analysis. The potential for cap failure, and the subsequent need to remove portions of the cap, due to unanticipated site conditions or events should be considered in selecting areas to be capped. Also, there are very little data that currently exist on the long-term success of ISC projects.

Table 2 summarizes important factors which may rule out capping as a viable alternative and the corresponding conditions for the Lower Fox River.

TABLE 2 SITE CONDITIONS THAT DO NOT FAVOR CAPPING AND THE CORRESPONDING CONDITIONS FOR THE LOWER FOX RIVER

Conditions Which May Rule Out ISC (NRC, 1997)	Corresponding Conditions for Lower Fox River
Contaminant sources have not been sufficiently abated to prevent re-contamination of the cap.	Sediments are considered the major source of PCBs in the Lower Fox River. External sources of PCB inflow have been controlled. The potential for recontamination is low if capping is implemented as part of an overall remedial program and in a downstream sequence.
Unacceptable risk of catastrophic failure due to wave events, flood events, ice scour, slope failure, or seismic events.	Placement of an armor layer will be required for scour protection; cap layer will not be placed at elevations susceptible to ice scour. Dam failure may be a potential concern, but the cap armor could be designed with a factor of safety.
Contaminant mobility and transport conditions cannot be effectively controlled by a designed cap (e.g., some combination of high contaminant concentrations, presence of non-aqueous phase liquids (NAPL), and advective groundwater flow conditions).	Potential for gas (methane) formation is high and cap design must consider potential to affect the integrity of the cap, and incorporate appropriate safety and monitoring factors into the final design. Available information indicates little potential for seepage due to groundwater to the River. However, cap design must demonstrate that there are no sand-stringers with groundwater recharge to the River.
Public use of groundwater, if surface water recharges a shallow aquifer underneath the contaminated sediment.	Potable water is drawn from a different aquifer ca. 400-foot depth, with no hydraulic connection to the shallow aquifer.
Unacceptable short-term risk posed by placement of the cap.	Short-term risk of cap placement is likely to be equivalent to or less than that associated with environmental removal. Resuspension by cap placement must be considered in selecting the methods and equipment.
Presence of infrastructure, such as piers, bridges, or pipelines, that is incompatible with a permanent cap.	Extensive debris, abandoned, and existing infrastructure occurs within OU 4. Debris may preclude the construction of a continuous and effective cap and must be well delineated and considered in a final cap design.
Cap is incompatible with water body uses, such as navigation, flood control, or recreation.	Navigation channels are present and will be maintained at appropriate depths; caps will not be placed in navigation channel areas.

1.3.5 Field Experience with Capping as a Sediment Remedy

A number of contaminated sediment sites have been remediated by ISC operations worldwide, and the experience base is growing rapidly. There has been a number of sediment capping projects in this country, mostly associated with USACE dredging or other non-Superfund projects. However, few projects to date have addressed capping highly contaminated sediment or highly mobile contaminants, or upward groundwater flow through a cap. In addition, most caps have been built within the last 10 years, and only a few of them have had intensive monitoring programs, so there are little data available on the long-term track record of contaminated sediment caps. However, the contaminant movement processes are for the most part well understood and tools are available to model the long-term behavior of contaminants under a cap.

A list of the major capping projects conducted to date is summarized in Table 3. With few exceptions, these projects have been located in North America. Almost all of the projects to date have been located in relatively deep, quiescent water bodies (e.g., lakes, estuaries, or ocean floor) and incorporated a relatively thick cap (ca. 18 inches or greater) based on consideration of physical mixing during placement, advective and diffusive flux, physical cap stability, and potential for bioturbation of the cap.

1.4 ISC Functions and Performance Objectives

ISC remedies must be considered engineered projects, designed to meet specific functions and performance objectives. The design must consider the nature of the Site and all processes acting at the Site, which may influence the cap from the standpoint of its physical stability and its ability to isolate contaminants. These are discussed below.

1.4.1 Capping Functions and Design Criteria

The goal of ISC is to reduce exposure of aquatic organisms to sediment contaminants, thereby reducing contaminant uptake and providing appropriate protection of human health and the environment.

ISC can address remediation through three primary functions:

- Physical isolation of the contaminated sediment from the aquatic environment;
- Stabilization of contaminated sediment, preventing resuspension and transport to other sites; and
- Reduction of the flux of dissolved and colloidally transported (i.e., facilitated transport) contaminants into surface cap materials and the overlying water column.

The selected functions for a cap and design criteria for a specific capping project should be framed to support Remedial Action Objectives (RAOs), Remediation Goals (RGs) or selected cleanup levels.

TABLE 3 SUMMARY OF CONTAMINATED SEDIMENT CAPPING PROJECTS

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance Results	Comments
Great Lakes Region							
Sheboygan River/Harbor Wisconsin	PCBs		composite of geotextile on fabric, 6" aggregate, geotextile, 6" cobble, with the perimeter anchored with gabions	armored stone composite	1989–1990	• Undetermined cap effectiveness • Some erosion of fine-grained material • WDNR/EPA order cap removal in ROD	Demonstration bench-scale project. Composite armored cap required as sediments were located in high-energy river environment. Gabions placed around the corners for anchoring. Additional course material placed into voids/gaps.
Wausau Steel Site Wisconsin	lead, zinc, mercury	Oxbow on the Big Rib River, nearshore cap	2	composite: sand over geotextile	1997	• Chemical isolation failed • Cap not physically stable	Methane gas trapped under the geotextile forced cap to rise in the center, pulling away geotextile from the edge. Sand erosion also occurred in the nearshore areas.
Manistique Capping Project Michigan (pilot)	PCBs		40-mil (0.1')	HDPE	1993	• Physical inspection of the temporary cap approximately 1 year after installation showed cap was physically intact and most anchors still in place, but was methane-filled	A 240' by 100' HDPE temporary cap was anchored by 38 2-ton concrete blocks placed around the perimeter of the cap. This temporary cap was installed to prevent erosion of contaminated sediments within a river hotspot with elevated surface concentrations.
Hamilton Harbor Ontario, Canada	PAHs		1.6	sand (2.5 acres) (*in situ*)	1995	• Chemical isolation effective • No erosion of cap	Cap monitoring in porewater ongoing.

TABLE 3 SUMMARY OF CONTAMINATED SEDIMENT CAPPING PROJECTS

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance Results	Comments
Puget Sound							
Duwamish Waterway Seattle, Washington	heavy metals, PCBs		1–3	sand (4,000 cy)	1984	• Chemical isolation effective • No erosion of cap	Monitoring as recent as 1996 showed cap remains effective and stable. Split-hull dump barge placed sand over relocated sediments (CAD site) in 70' water.
One Tree Island Olympia, Washington	heavy metals, PAHs		4	sand	1987	• Chemical isolation effective • No erosion of cap	Last monitoring occurred in 1989 showed that sediment contaminants were contained.
St. Paul Waterway Tacoma, Washington	phenols, PAHs, dioxins		2–12	coarse sand	1988	• Chemical isolation effective • Cap within specifications	Some redistribution of cap materials has occurred, but overall remains >1.5 m (4.9'). *C. californieus* found in sediments, but never >1 m (3.3').
Pier 51 Ferry Terminal Seattle, Washington	mercury, PAHs, PCBs		1.5	coarse sand (4 acres) (*in situ*)	1989	• Chemical isolation effective • Cap within specifications • Recolonization observed	As recent as 1994, cap thickness remained within design specifications. While benthic infauna have recolonized the cap, there is no indication of cap breach due to bioturbation.
Denny Way CSO Seattle, Washington	heavy metals, PAHs, PCBs	water depth 18'–50'	2–3	sand (3 acres)	1990	• Chemical isolation effective • Cap within specifications • Recolonization observed	Cores taken in 1996 show that while cap surface chemistry shows signs of recontamination, there is no migration of isolated chemicals through the cap.
Piers 53–55 CSO Seattle, Washington	heavy metals, PAHs		1.3–2.6	sand (4.5 acres) (*in situ*)	1992	• Chemical isolation effective • Cap stable, and increased by 15 cm (6") of new deposition	Pre-cap infaunal communities were destroyed in the rapid burial associated with cap construction, but had recovered by 1996. The initial community established in the sand over time shifted as fine-grained material was redeposited on the cap.
Pier 64 Seattle, Washington	heavy metals, PAHs, phthalates, dibenzofuran		0.5–1.5	sand	1994	• Some loss of cap thickness • Reduction in surface chemical concentrations	Thin-layer capping was used to enhance natural recovery and to reduce resuspension of contaminants during pile driving.
GP lagoon Bellingham, Washington (*in situ*)	mercury	shallow intertidal lagoon	3	sand	2001	• Chemical isolation effective at 3-months • Cap successfully placed	Ongoing monitoring.
East Eagle Harbor/Wyckoff Bainbridge Island, Washington	mercury, PAHs		1–3	sand (275,000 cy)	1994	• Chemical isolation effective • Cap erosion in ferry lanes • Some recontamination observed due to off-site sources	Cap erosion measured within first year of monitoring only in area proximal to heavily-used Washington ferry lane. Chemicals also observed in sediment traps. Ongoing monitoring.
West Eagle Harbor/Wyckoff Bainbridge Island, Washington (*in situ*)	mercury, PAHs	500-acre site	Thin cap 0.5' over 6 acres and thick cap 3' over 0.6 acre	sand (22,600 tons for thin cap and 7,400 tons for thick cap)	partial dredge and cap 1997	• Chemical isolation effective	To date, post-verification surface sediment samples have met the cleanup criteria established for the project. Ongoing monitoring.

TABLE 3 SUMMARY OF CONTAMINATED SEDIMENT CAPPING PROJECTS

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance Results	Comments
California and Oregon							
PSWH Los Angeles, California	heavy metals, PAHs		15	sand	1995	• No data to date	Overall effective cap was >15'. This was not a function of design, but rather a function of the low contaminated-to-clean sediment volume.
Convair Lagoon San Diego, California	PCBs	5.7-acre cap in 10-acre site; water depth 10'–18'	2' of sand over 1' rock	sand over crushed rock	1998	• Chemical isolation effective • Cap was successfully placed • Some chemicals observed in cap	Ongoing monitoring for 20 to 50 years including diver inspection, cap coring, biological monitoring.
McCormick and Baxter Portland, Oregon	heavy metals, PAHs	15 acres of nearshore sediments and soils	NA	sand	planned, but not constructed	• No data to date	Long-term monitoring, OMMP, and institutional controls were also specified.
New England/New York							
Stamford-New Haven-N New Haven, Connecticut	metals, PAHs		1.6	sand	1978	• Chemical isolation effective	Cores collected in 1990.
Stamford-New Haven-S New Haven, Connecticut	metals, PAHs		1.6	silt	1978	• Chemical isolation effective	Cores collected in 1990.
New York Mud Dump Disposal Site New York	metals (from multiple harbor sources)		unknown	sand (12 million cy)	1980	• Chemical isolation effective	Cores taken in 1993 (3.5 years later) showed cap integrity over relocated sediments in 80' of water.
Mill-Quinniapiac River Connecticut	metals, PAHs		1.6	silt	1981	• Required additional cap	Cores collected in 1991.
Norwalk, Connecticut	metals, PAHs		1.6	silt	1981	• No problems	Routine monitoring.
Central Long Island Sound Disposal Site (CLIS) New York	multiple harbor sources		unknown	sand	1979–1983	• Some cores uniform structure with low-level chemicals • Some cores chemical isolation effective • Some slumping	Extensive coring study at multiple mounds showed cap stable at many locations. Poor recolonization in many areas.
Cap Site 1 Connecticut	metals, PAHs		1.6	silt	1983	• Chemical isolation effective	Cores collected in 1990.
Cap Site 2 Connecticut	metals, PAHs		1.6	sand	1983	• Required additional cap	Cores collected in 1990.
Experimental Mud Dam New York	metals, PAHs		3.3	sand	1983	• Chemical isolation effective	Cores collected in 1990.
New Haven Harbor New Haven, Connecticut	metals, PAHs		1.6	silt	1993	• Chemical isolation effective	Extensive coring study.
Port Newark/Elizabeth New York	metals, PAHs		5.3	sand	1993	• Chemical isolation effective	Extensive coring study.

TABLE 3 SUMMARY OF CONTAMINATED SEDIMENT CAPPING PROJECTS

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance Results	Comments
52 Smaller Projects New England	metals, PAHs		1.6	silt	1980–1995	• Chemical isolation effective	Routine monitoring.
Other North American Projects							
Soda Lake, Wyoming	oil refinery residuals	soft, uncon-solidated sediments	3	sand	2000	• Chemical isolation effective	Demonstration project that showed successful placement over soft sediments and isolation of PAHs and metals in refinery residuals.
International Projects							
Rotterdam Harbor Netherlands	oils	water depth 5 to 12 m	2–3	silt/clay sediments	1984	• No available monitoring data	As pollution of groundwater was a potential concern, the site was lined with clay prior to sediment disposal and capping.
Hiroshima Bay Japan		Water depth 21 m	5.3	sand	1983	• No available data	

References:

EPA, 1998. *Manistique River/Harbor AOC Draft Responsiveness Summary, Section 4: In-place Containment at Other Sites*. Sent by Jim Hahnenberg of United States Environmental Protection Agency Region 5 and Ed Lynch of Wisconsin Department of Natural Resources on September 25, 1998.

King County Water and Land Resources Division, 1997. *Pier 53–55 Sediment Cap and Enhanced Natural Recovery Area Remediation Project*. 1996 Data Report. Panel Publication 17. Prepared for the Elliott Bay/Duwamish Restoration Program Panel.

SAIC, 1996. *Year 11 Monitoring of the Duwamish CAD Site, Seattle, Washington*. Report prepared for the United States Army Corps of Engineers, Seattle District by Science Applications International Corporation, Bothell, Washington.

Sumeri, A., 1984. Capped in-water disposal of contaminated dredged material: Duwamish Waterway site. In: *Proceedings of the Conference Dredging '84, Dredging and Dredged Material Disposal, Volume 2*. United States Army Corps of Engineers, Seattle, Washington.

Truitt, C. L., 1986. *The Duwamish Waterway Capping Demonstration Project: Engineering Analysis and Results of Physical Monitoring*. Final Report. Technical Report D-86-2. United States Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. March.

USACE, 1995. *Sediment Capping of Subaqueous Dredged Material Disposal Mounds: An Overview of the New England Experience 1979–1995*. Special Technical Report Contribution 95. United States Army Corps of Engineers, New England Division, Disposal Area Monitoring System (DAMOS). August.

If reduction in flux is an intended function of the cap, the following processes should be considered when evaluating the potential effectiveness of a cap and in developing design criteria for the cap:

- Upward contaminant flux rates (mass of contaminant/unit area/unit time);
- Pore water concentrations (dissolved or colloidal);
- Potential changes in redox potential (contaminant chemistry) due to cap placement;
- Long-term accumulation of contaminants in cap material;
- Contaminant breakthrough as a function of time; and
- Ability of the cap to withstand bioturbation and erosive forces.

For example, contaminant flux and the resulting impact on cap surface materials, cap pore water, or overlying water quality can be compared to site-specific sediment cleanup levels or water quality standards (e.g., federal ambient water quality criteria or state-promulgated standards). In addition, the concentration of contaminants accumulating in the cap material as a function of time can be compared to site-specific target cleanup levels during long-term cap performance monitoring. The design should also be compatible with available construction and placement methods, and the mitigation of potential habitat impacts during construction.

1.4.2 Lower Fox River Design and Performance Criteria

For the Lower Fox River, the design criteria for capping should include the following:

- Technical, regulatory and institutional issues will be appropriately considered in identifying potential areas for capping.
- The cap will be designed to provide physical isolation of the PCB-contaminated sediments from benthic organisms.
- The cap will be physically stable from scour by currents, flood flow, and ice scour. The 100-year flood event will be considered in these evaluations.
- The cap will provide isolation of the PCB-contaminated sediments in perpetuity from flux or resuspension into the overlying surface waters. The performance criteria for chemical isolation will be a limit of 250 parts per billion (ppb) of PCBs in the cap sediment (dry-weight basis) in the biologically active zone, defined as the upper 10 centimeters (cm) of the isolation layer of the cap. This standard would apply as a construction standard to ensure the cap is initially placed as a clean layer, and would also apply as a long-term limit with respect to chemical isolation.

- The cap design will consider operational factors such as the potential for cap and sediment mixing during cap placement and variability in the placed cap thickness.

- The cap design will incorporate an appropriate factor of safety to account for uncertainty in Site conditions, sediment properties, and migration processes.

2 SITE AND SEDIMENT CHARACTERISTICS

Site conditions, more than any other consideration, will determine the feasibility and effectiveness of ISC. Site characteristics affect all aspects of a capping project, including design, equipment selection, and monitoring and management programs. Some limitations in site conditions can be accommodated in the ISC design. A thorough examination of site conditions should determine if further consideration of ISC is appropriate. For the Lower Fox River, site characteristics will dictate which areas can be potentially capped within the OUs.

Aspects of site characterization important for ISC include the following:

- Physical environment;
- Hydrodynamic conditions;
- Geotechnical/geological conditions;
- Hydrogeological conditions;
- Sediment characteristics; and
- Waterway uses.

Each of these are discussed in the context of the Lower Fox River in the following sections.

2.1 PHYSICAL ENVIRONMENT

Regional, climate, and basic environmental settings for the project are important considerations as well as specific physical environmental characteristics as they may relate to cap design. The Lower Fox River is a well-studied system with a large data set that is summarized in the *Remedial Investigation for the Lower Fox River and Green Bay, Wisconsin* (RI) (RETEC, 2002b). The basic environmental setting for the Lower Fox River is a controlled series of locks and dams, with the exception of the last OU of the River. The level of control is high for OUs 1, 2, and 3, but less so for OU 4. The dimensions of the waterway are not generally a constraint to capping except for certain limitations regarding water depth.

Other physical environment considerations that are of importance for the Lower Fox River include long-term lake level fluctuations; the presence of several bridge and infrastructure crossings; and a number of piers, docks, and other shoreline structures. The locale of the Lower Fox River is subject to ice formation, and the effects of ice scouring must be considered. The relevance of each of these considerations and the site-specific conditions for the Lower Fox River are discussed below.

2.1.1 Water Depth and Bathymetry

Water depths and seiche patterns could limit cap construction options and will affect cap design and waterway uses. The potential for ice scour and habitat characteristics are the two most important considerations related to water depth for capping on the Lower Fox River. WDNR has indicated that ice scour could be a constraint on cap placement in water depths of 3 feet or less. Carp habitat is considered undesirable for the Lower Fox River, and to discourage its creation, a minimum water depth of 3 feet should be maintained. Long-term lake level changes (from +5 to -1) should be accounted for in designing for these restrictions for OU 4. Considering these restrictions, no cap should be constructed with a surface above -3 feet chart datum in OUs 1 and 3, and above -4 feet chart datum in OU 4. Removal may therefore be required prior to ISC placement in shallow-water areas.

With the exception of the bank areas, bathymetry of the Lower Fox River is relatively flat and should present no restrictions on cap placement. Steeper slopes are evident near the banks, but bank areas represent only a small percentage of the total area to be remediated.

The water depths in OU 1 are generally shallow (less than 6 feet) throughout the area to be remediated and may present some constraints for equipment access for cap placement. Shallow draft barges for movement of cap material or hydraulic placement methods using pipeline could be considered. The other two operable units do not have any general depth restraints for capping.

2.1.2 Hydrodynamic Conditions

Capping projects are easier to design in low-energy environments (e.g., protected harbors, low-flow streams, or estuarine systems). In open water, deeper sites will be less influenced by wind or wave-generated currents, and are generally less prone to erosion than shallow, nearshore environments. However, armoring techniques or selection of erosion-resistant capping materials can make capping technically feasible in some high-energy environments.

Hydrodynamic conditions differ between OUs 1, 3, and 4, but the site can be generally characterized as a low-energy environment. Although the Lower Fox River is an alluvial river and sediments are subject to transport during flood events, the presence of locks and dams provides for a controlled environment. The lower portion of OU 4 is open to Green Bay and is subject to seiches and long-term lake level changes.

The shear stress distribution during flood events has been modeled (HydroQual, 2000; LTI, 2002). However, there are some differences between the modeling efforts regarding interpretations of data and the resulting erosion potential. The shear stresses predicted to occur during flood events indicates that the use of erosion-resistant materials (armor layers) for the upper portions of the cap will be needed. Since the shear stress varies significantly with geometry across the River cross section and upstream to downstream within OUs, a single armor design over the entire project is not sufficient.

The hydrodynamics of the Lower Fox River should be definitively evaluated as part of the detailed design for the armor component of the cap. This design should be based on an evaluation of a 100-year flood event.

The presence of an ISC can alter existing hydrodynamic conditions. So, the flow-carrying capacity of the River should also be evaluated for the post-remedy condition (with removal and capping components considered).

2.1.3 Sedimentation

In a net depositional environment, the effect of new sediment deposited on the cap should be considered. Clean sediment accumulating on the cap or in voids within an armor layer can increase the isolation effectiveness of the cap over the long term. Accumulation of contaminated sediment from off-site sources can result in a contaminated surface layer over the cap. The sources of PCBs would be controlled for the system by implementing the construction of any remedy progressing from upstream to downstream. Deposition of new sediment should be considered when designing the monitoring program.

2.1.4 Dam Safety and the Potential for Dam Removal

The safety of the dams with respect to potential failure is an issue for cap placement and design of the armor layer for the cap. Furthermore, the removal of a dam for safety or environmental reasons should be considered in cap design, and in the long-term institutional requirements for cap operations and monitoring.

As noted previously, the hydrodynamics of the Lower Fox River are influenced by the series of locks and dams on the River. Within Wisconsin, there are approximately 3,700 dams. An additional 700 dams have been built and washed out or removed since the late 19th century, and approximately 100 dams have been removed since 1967. On the Lower Fox River, there are 13 existing dams and 1 abandoned dam. As documented in *White Paper No. 4 – Dams in Wisconsin and on the Lower Fox River* (WDNR, 2002a), the current condition of the dams is stable. Recent inspection reports by the USACE indicate that the spillway and sluiceway sections of the dams have adequate compression to resist overturning and have adequate bearing capacity to support the maximum base pressure. While inspections did reveal various potential problems, such as the need for concrete repairs, the overall conclusion of the reports was that dams were found to be in good condition overall and no structural deficiencies were found which would affect the operation of the dam. Many of the inspection reports recommended development of a plan to prioritize the repairs for the dams on the Lower Fox River over a subsequent 5-year period.

The three major reasons for dam removals in Wisconsin are:

- Removal of an unsafe structure under Chapter 31.19 of state statutes. Under Chapter 31.19, the WDNR is required to inspect "large" dams at least once every 10 years to ensure their safety.
- Chapter 31.187 charges the WDNR with removing "abandoned" dams when either no owner is found, or the owner or owners are not able to fund repairs.
- In a few cases, the state has removed, or proposed to remove, dams that have a significant environmental impact. Many of those have been on WDNR properties.

While dam removal is not imminent or planned along the Lower Fox River, dam removal considerations are evident in two national PCB sediment programs. On the Hudson River, the Fort Edward dam was removed in 1973 due to structural instability. The so-called remnant deposits in the Hudson River are areas of former river bottom that became exposed due to changes in the water level following removal of the dam (EPA, 1984). Changes in the hydrology after dam removal resulted in the downstream release of an estimated 1,300,000 cy of PCB-laden sediment (NOAA, 2002).

In Michigan, a series of dams are under consideration for removal on the Kalamazoo River (USGS, 2001). Removal of these dams will return the Kalamazoo River to its pre-dam flow, increase recreation uses and safety of the River, and improve aquatic habitat in that section of the River. However, there are large volumes of PCB-contaminated sediments within the impoundments behind the dams; the Michigan Department of Environmental Quality, EPA, and the USGS are all involved in evaluating the management of those sediments if dam removal were to occur.

Any consideration for an ISC on the Lower Fox River should consider the maintenance of the dam/lock system as an institutional control with requirements for maintenance of the system in perpetuity. It is worth noting that this requirement was similarly considered for breakwaters in evaluating capping as an option for Manistique Harbor. As an alternative, the ISC cap design should include a component for safe isolation if dam removal results in the creation of remnant deposits.

2.1.5 Geological and Hydrogeological Conditions

The geological conditions within the Lower Fox River are well documented in Section 3 of the RI, and are not discussed here. Pertinent to any capping evaluation is the thickness of contaminated sediments. Within OU 1, the major deposits are generally between 1 and 3 feet of accumulated sediments. In OU 3, the longest deposit, EE, ranges up to 7.5 feet in thickness, while accumulations immediately behind the De Pere dam exceed that. Within OU 4, sediment thickness varies with approximately 3-foot accumulations closer to the dam, and 12 to 19 feet of accumulation in the areas proximal to the turning basin.

A detailed evaluation and understanding of the site's hydrogeology is a critical component in evaluating the acceptability of an ISC and a prerequisite to proper cap design. The presence of an upward groundwater gradient at the site would require that the cap be designed to accommodate advective processes related to contaminant migration.

The Lower Fox River is fairly well documented to have either relatively nonporous clay or bedrock underlying most of the River. However, the area does include sand stringers or fractured bedrock; these would need to be considered during sampling for design purposes. Available information indicates little potential seepage (advection) due to groundwater flow, so no continuous advective flow processes need be considered for the cap design. However, the process of consolidation-induced advection will occur and should be considered in the cap design.

2.2 SEDIMENT CHARACTERISTICS

2.2.1 Sediment Physical Properties

Physical characteristics of the River and Green Bay are presented in detail in Section 3 of the RI. In general, sand and silt are the dominant grain sizes in the River sediments, typically accounting for between 75 and 90 percent of the particles present. In OUs 1, 2, and 4, silts comprise about 40 percent of the sediments, while sand content ranges between 41 and 46 percent. In OU 3, however, the silt content is 54 percent, while sand comprises only about 23 percent of the sediments. Within a single unit, the distributions are variable. For example, within OUs 1 and 4 the grain size may average between 36 and 40 percent sand, but the individual samples collected show a range from 0.5 to 98 percent sand.

One of the barriers to effective cap design is the general lack of data taken on physical parameters, such as bulk density, percent moisture, Atterberg limits, and the absence of any data from self-consolidation tests. Only a limited number (less than 20 data points) of these data exist, and thus it is difficult to assign specific design and performance properties at this stage. It will be necessary to acquire those data prior to finalizing any ISC design for the River. From the data in hand, however, two points are clear: (1) no single design will be adequate for the entire River and the cap engineering will need to be specific to the deposit intended, and (2) caps have been successfully implemented over sediments that have similar physical properties to those found on the Lower Fox River.

2.2.2 Extent of Contamination

The physical, chemical, and biological characteristics of the contaminated sediment, both horizontally and vertically, have been defined in Section 5 of the RI. Within the Proposed Plan, WDNR and EPA defined the Remedial Action Level (RAL) as 1 ppm, with an expected surface-weighted average concentration within each OU of between 0.25 and 0.35 ppm. For OUs 1 and 3, over 90 percent of PCB mass is in the upper 1 meter of sediment. In OU 4, 90 percent of the PCB mass is in the upper 2 meters of sediment (in 60 percent of OU 4, the average depth of dredging to the 1,000 ppb concentration is the top meter, 90 percent in the top 2 meters) is generally in the upper few feet of sediment. New data for OU 1 submitted with the public comments was evaluated in *White Paper No. 2 – Evaluation of New Little Lake Butte des Morts PCB Sediment Samples* (WDNR, 2002b). An analysis of these data concluded that the new information did not alter the current understanding of the general conditions within the unit, nor substantively effect the need for remedial actions.

The presence of PCBs with concentrations exceeding 50 ppm presents some constraints for capping with respect to TSCA. The ability of an ISC to meet the requirements of TSCA has not been fully established. TSCA-level sediments are present only in limited areas of OUs 1, 3, and 4. Based on these considerations, no capping of TSCA-level sediments should be considered.

Additional sampling at a greater degree of resolution will be needed for the design phase.

2.2.3 Shear Strength

Shear strength of contaminated sediment deposits is of particular importance in determining the feasibility of ISC from the standpoint of cap placement. The soft sediments will require due care in selecting placement techniques and management of capping operations. No shear strength data have yet been collected. Vane shear data should be collected during the design phase to determine the distribution of shear strengths by area and vertically within the sediment profile.

2.2.4 Gas Formation

When contaminated materials or sludges containing organic material are capped, the organic material could begin to decompose under the influences of anaerobic and pressure-related processes. The products of this decomposition process will consist mainly of methane and hydrogen sulfide gases. As these dissolved gases accumulate and transfer into a gaseous phase, they could begin to percolate through the capped matrix by convective or diffusive transport. This transport of gases percolating through the cap can facilitate a more rapid contaminant migration by providing avenues for contaminant release or solubilizing the contaminants of concern, carrying them through the saturated porous media dissolved in the gaseous molecules.

Methane generation must be considered for the Lower Fox River. The Lower Fox River has a high methane sediment that is documented in the 1996 RI/FS (GAS/SAIC, 1996). Sub-bottom profiles of sediments revealed large subsurface accumulations of methane in OUs 1, 2, and 3. Methane releases are frequently observed during sediment sampling, and were seen during the demonstration project at SMU 56/57.

2.2.5 Debris and Obstructions

Debris is present in the nearshore areas of the OUs, especially in OU 4. Debris may preclude the construction of a continuous and effective cap and must be well delineated and considered in a final cap design. A side-scan sonar survey is planned to determine the extent of debris in the sediment.

2.3 WATERWAY USES

2.3.1 Flow Capacity

Placement of a cap (without prior removal action) will reduce water depths and the flow carrying capacity of the River. Chapter 116, Wisconsin Administrative Code, Wisconsin's Floodplain Management Program, details the regulations for construction and development in floodways and floodplains. Any proposed cap would have to meet the substantive requirements of Section 116.16(1), which requires that structures built within floodways and floodplains must be built to withstand flood depths, pressures, velocities, impact, uplift forces, and other factors associated with the regional (100-year) flood. In addition, any cap proposed would be required to undertake a determination on the potential effects on the regional flood heights. This would require a substantive study on the hydrologic and hydraulic conditions pre- and post-construction to determine if there would be an increase in flood height due to cap placement. NR 116.03(28) defines an "increase in regional flood height" as being equal to or greater than 0.01 foot if a cap would result in an increase in regional flood height.

2.3.2 Navigation and Recreational Use

A navigation channel system exists in OUs 1, 3, and 4 which must be considered in determining potential capping areas. The USACE maintains an 18-foot-deep commercial channel in OU 4. For OUs 1 and 3, the USACE no longer maintains the authorized channel depth and there is no longer commercial traffic in these OUs. However, the WDNR has indicated that there will be future demand to maintain a 6-foot deep channel in OUs 1 and 3 for recreational use. Based on these considerations, there does not appear to be any need to consider modifying the authorization from commercial to recreational, if the state wishes to maintain the recreational channel depth. The continued demand to maintain the existing channel depths would preclude cap placement within the channel areas.

The acceptable draft of vessels allowed to navigate over a capped area depends on water level fluctuations and the potential effects of vessel groundings on the cap. Due to potential cap erosion caused by propeller wash, engine size restrictions could also be needed. Anchoring should not be allowed at locations on or near the ISC site. Fishing and swimming may have to be restricted to avoid vessels from dragging anchors across the cap.

2.3.3 Infrastructure

Utilities (storm drains) and utility crossings (water, sewer, gas, oil, telephone, cable, and electrical) are commonly located in urban waterways. Existing utility crossings under portions of waterways to be capped may have to be relocated if their deterioration or failure might impact cap integrity or if they could not be repaired without disturbing the cap. Future utility crossing could be prohibited in the cap area. The presence of the cap can also place constraints on any future waterfront development that could require dredging in the area.

Infrastructure considerations for the Lower Fox River which could affect selection of areas to be capped and future cap integrity and maintenance include the following:

- Water supply intakes;
- Stormwater or effluent discharge outfalls;
- Utilities and utility crossings; and
- Construction of bulkheads, piers, docks, and other waterfront structures.

To date, environmental agencies have little experience with the ability to enforce use restrictions necessary to protect the integrity of an ISC (e.g., vessel size limits, bans on anchoring, etc.). Voluntary restrictions on public land and water use will likely be ineffective local enforcement of specific use restrictions is the desired outcome. Compliance, enforcement, and the effectiveness of these measures, and the consequences of non-compliance should be considered.

2.3.4 Habitat Considerations

ISC will alter the aquatic environment. Both potential improvement in habitat and change in the habitat type should be considered in evaluating and designing a capping alternative, wherever possible. However, it is important to remember that under CERCLA, the principal consideration is protection of human health and the environment, and capping is principally considered a remediation strategy. If a cap can be designed with beneficial habitat characteristics, that is a positive added benefit. In the case of the Lower Fox River, there is a separate Natural Resource Damage Assessment process that will address habitat restoration throughout the River and Green Bay. Nevertheless, this section does cover some habitat considerations for capping.

Where possible, the cap design should consider habitat for bottom-dwelling organisms or wetland wildlife. The desirable habitat characteristics will vary by location. In marine or estuarine environments, simply providing a layer of appropriately sized rock or rubble that can serve as hard substrate for attached molluscs (e.g., oysters or mussels) can enhance the ecological value. In freshwater systems, sand is neither a suitable substrate for benthic or epibenthic organisms, or for establishing submerged or emergent aquatic vegetation. A mix of cobbles and boulders can be chosen for aquatic environments in areas with substantial flow in order to support diverse assemblages of benthic infauna (e.g., Ephemeroptera, Plecoptera and Trichoptera) that in turn are prey for numerous fish species. The project manager should consult with local resource managers or natural resource trustee agencies to determine what types of modifications to the cap surface would provide suitable substrate for local organisms.

No matter what modification is desirable, the potential for attracting burrowing organisms incompatible with the cap design or ability to withstand additional physical disturbances should be considered. Habitat enhancements should not impair the function of the cap or its ability to survive storms, flooding, or propeller wash.

The Lower Fox River is a freshwater system, and the habitat is largely dominated by soft sediments. A cap as a habitat enhancement or detriment will depend upon the elevation of the final cap surface, the current velocity at the specific location, and the type of material selected for the armored surface. For example, a course sand cap placed in deeper portions of Little Lake Butte des Morts (greater than 4 feet) is more likely to be a short-term detriment, as sand does not provide habitat to benthic organisms that support fish species. A fine gravel armor in a low-velocity area of the River will not provide suitable substrate for benthos, nor would it serve as a spawning habitat for walleye because of sedimentation over eggs. Raising the river bottom by capping to shallow depths (less than 3 feet) would also have a detrimental effect, as it would create additional carp habitat. The short-term net environmental effect of that cap would also be negative, eliminating soft-sediment benthic production.

The importance of habitat to the River and Green Bay is evident in the advocacy by the Green Bay Remedial Action Plan for improved habitat in the form of extensive areas of rooted aquatics. Centrarchid (bass, crappie, sunfish) production is low within the Lower Fox River. The limiting factor for centrarchid production in the River is the general lack of rooted aquatic macrophyte beds that provide early life-stage habitat (Becker, 1983; Lychwick, personal communication).

In appropriately selected areas, armoring could enhance fish habitat. Walleye in the Lower Fox River and Green Bay prefer to spawn over large gravel and cobble with the greatest success occurring over 2- to 6-inch material (Lychwick, personal communication). This material was successfully employed by the WDNR in construction of walleye spawning enhancement areas in the River below the De Pere dam.

Alteration of habitat by cap placement is an issue for the Lower Fox River which will present a constraint with respect to reduction of water depths. Water levels should remain 3 feet or greater to discourage carp habitat and ice scour (see discussion above for water depth constraints). Long-term lake level changes should also be accounted for. Lake level changes generally vary from elevation +5 to -1 foot chart datum. Based on these factors, no cap can be constructed with a surface elevation above -4 feet chart datum. (Note that present GIS map is tied to -3 feet below chart datum.)

2.4 CONSIDERATIONS FOR SELECTING CAPPING AREAS FOR THE LOWER FOX RIVER

Based on the above site and sediment characteristics, the following constraints in defining proposed locations suitable for capping within OUs 1, 3, and 5 are provided:

- Outside of navigation channels (with an appropriate buffer) to allow for future slope dredging;
- Outside of areas with interfering infrastructure such as pipelines, utility easements, bridge piers, etc. (with an appropriate buffer);
- PCB concentrations below TSCA levels; and
- Sufficient water depth such that the cap surface elevation would be no greater than -3 feet chart datum for OUs 1 and 3 and -4 feet chart datum for OU 4 without prior deepening to allow for cap placement.

3 *IN-SITU* CAP DESIGN AND CONSTRUCTION

To meet remedial goals and objectives, an ISC project must be treated as an engineering project, with careful consideration to design, construction, and monitoring. Site-specific constraints must be considered when selecting construction methods and capping materials. Construction should conform to project specifications. Cap improvements may be necessary to address field constraints and other requirements. Short-term risks can increase on- or off-site during and immediately following remediation due to construction-related disturbance and potential for contaminant transport. Therefore, designs must include plans to mitigate and monitor impacts during and after construction.

The composition, dimensions, and thickness of the components of a cap can be referred to as the cap design. This design should address the intended functions and design or performance standards of the cap. The general steps for ISC design are shown in the flowchart on Figure 3, and include the following:

- Identify candidate capping materials and compatibility with contaminated sediment at the site;

- Assess the bioturbation potential of local bottom-dwelling organisms, and design a cap component to physically isolate sediment contaminants from them;

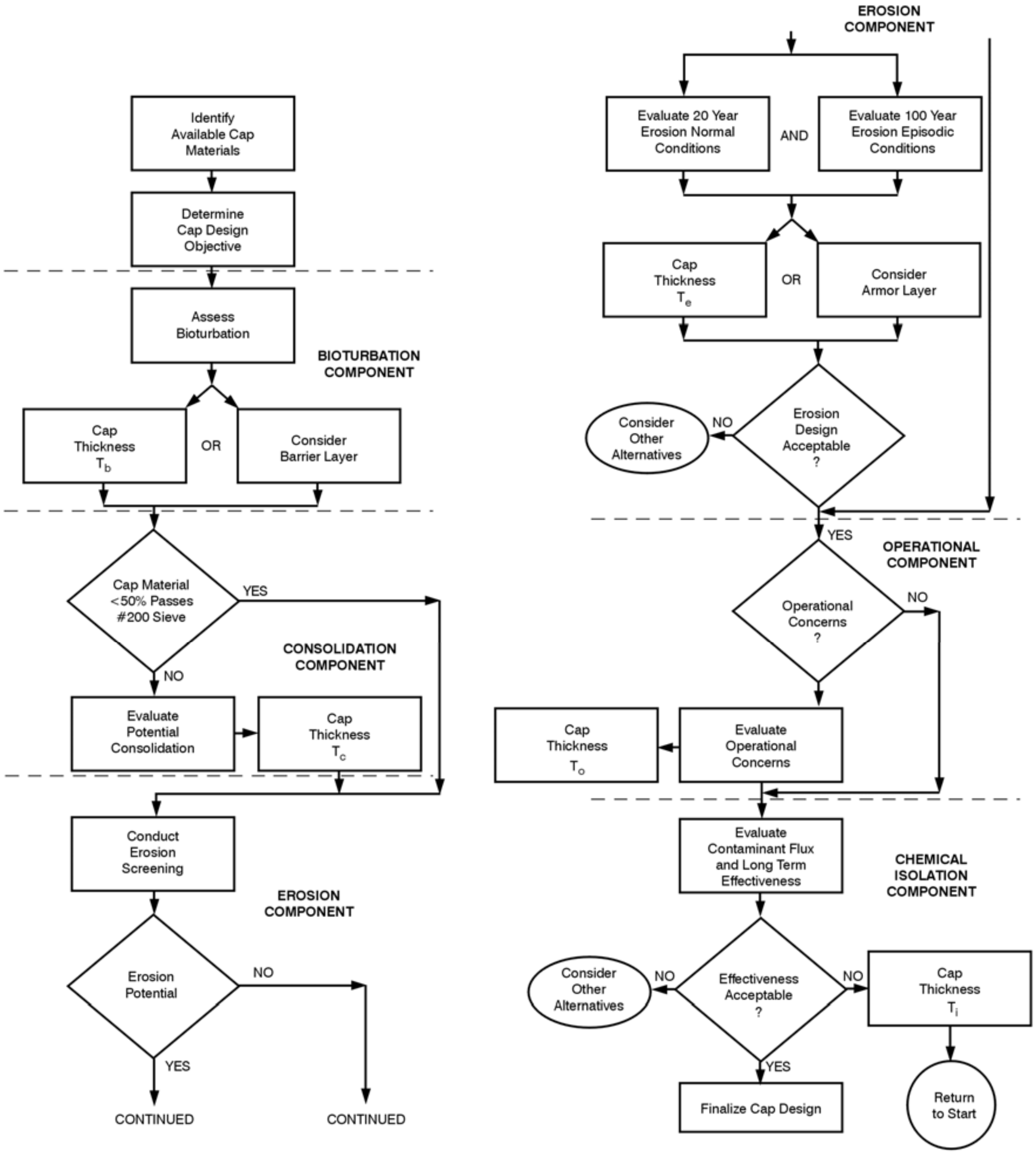
- Evaluate the potential erosion at the capping site due to currents, waves, ice scour, and propeller wash, and design a cap component to stabilize the contaminated sediment and other cap components;

- Evaluate the potential flux of sediment contaminants, and design a cap component to reduce the flux of dissolved contaminants into the water column;

- Evaluate the potential interactions and compatibility among cap components, including mixing and consolidation of compressible materials; and

- Evaluate the operational considerations and determine restrictions or additional protective measures (e.g., institutional controls) needed to ensure cap integrity.

FIGURE 3 *IN-SITU* CAP DESIGN FLOWCHART



T_t = Total Cap Thickness

T_b = thickness for bioturbation

T_c = thickness for consolidation

T_e = thickness for erosion

T_o = thickness for operational considerations

T_i = thickness for physical/chemical isolation

$$T_t = T_b + T_c + T_e + T_o + T_i$$

Both the FS and the Panel Report assume or propose a generic, representative cap design. Neither of these designs was evaluated in sufficient detail to constitute a "final" design suitable for all OUs of the River under all critical conditions. Similarly, it is not the purpose of this White Paper to present a proposed final design. Rather, design requirements and considerations are discussed here and needs for the final design are presented.

3.1 IDENTIFICATION/SELECTION OF CAPPING MATERIALS

Caps are generally composed of clean granular materials, such as sediment or soil; however, more complex cap designs could be required to meet site-specific RAOs. The design should consider the need for effective short- and long-term chemical isolation of contaminants, bioturbation, consolidation, erosion, and other related processes. For example, if the potential for erosion of the cap is significant, the cap thickness could be increased using a material with larger grain size, or an armor layer could be incorporated into the design. Porous geotextiles do not contribute to contaminant isolation, but serve to reduce the potential for mixing and displacement of the underlying sediment with the cap material. Geotextiles can also add structural support during cap placement. A cap composed of naturally occurring sand is generally preferred over quarry run sand, because the associated fine fraction and organic carbon content found in natural sands are more effective in providing chemical isolation by sequestering contaminants as they pass through the cap. Also, specialized materials may be considered for caps to enhance the chemical isolation capacity. Examples include engineered clay aggregate materials (e.g., AquaBlok™ or geosynthetic clay liners). These approaches are recent developments. However, the potential for gas generation may inhibit or prohibit use of impermeable components such as AquaBlok™ or membranes. Examples of cap designs considered and used for ISC are illustrated on Figure 1.

In designing cap thickness, consideration has to be given to the relative grain size, which affects the overall permeability of the ISC. In general, medium to fine sands have been used for ISCs. For example, the East Eagle Harbor Superfund Site ISC was constructed using medium sand (0.125 to 0.25 mm) dredged from within a river (EPA and USACE, 1995). Other recent ISC projects in the west/midwest have used a sand specification as follows:

Sieve	Percent Passing
#40 (0.425 mm)	99
#60 (0.25 mm)	20
#200 (0.075 mm)	3

This material could be described as a poorly graded fine sand. In at least one case, where finer sands were not commercially available, the design was modified to allow placement of somewhat coarser material for the initial 15 inches in a 24-inch cap, and then a layer of finer masonry sand at the surface.

Compared to granular materials typically specified for routine construction projects in Wisconsin, it would be somewhat finer and with less of a coarse fraction and it may be somewhat rare to find this material as a natural bank. Within the Fox Valley, a variety of sand products are produced, and include both natural "bank run" material and "manufactured" material (from the crushing and processing of rock). As a result, a range of grain size distributions can generally be obtained, with correspondingly higher or lower amounts of coarse material and fines.

Cap materials for the Lower Fox River are assumed to be granular materials (sands, gravels, or stone) available from commercial sources. An initial inquiry into local sources indicates that at least one company is currently supplying a product that would meet the above specification at fairly low cost (e.g., less than $3 per cy, loaded but not delivered). In general, though, because this particular specification may routinely require a higher level of processing, an appropriate budgetary range, including transportation, may be in the range of $8 to $10 per ton.

A total organic carbon (TOC) content for cap material of 0.5 percent by weight will result in adequate binding capacity for hydrophobic contaminants such as PCBs (Palermo et al., 1998a). A minimum TOC concentration of 0.5 percent has been specified for a number of ongoing and proposed projects, and is considered appropriate for the Lower Fox River. Addition of TOC in the form of granulated carbon is anticipated to raise the sand cap TOC to 0.5 percent by dry weight.

3.2 CAP COMPONENTS AND THICKNESSES

For a major Superfund site such as the Lower Fox River, an appropriate level of conservatism should be considered in approaching the cap design. The total thickness of a cap and the composition of the cap components should be based on an evaluation of all the pertinent processes for the site and the ability of the design to achieve the intended functions of the cap. Processes that should be considered include physical isolation of benthic organisms, bioturbation, cap consolidation, erosion, operational factors, and chemical isolation. Some of the processes for design of cap components can be evaluated rigorously with models, etc., but others require engineering judgment. Cap design is evolving as more experience is gained across the range of project conditions. For cap design with a granular material, a conservative "layer approach" is recommended. As shown on Figure 3, each component is considered, and the necessary cap thickness is assumed as the sum of the layers for each component, with no dual function for the same cap component. For an armored cap with the surface layer composed of gravel or stone, the erosion protection layer may also act effectively as the bioturbation component, so a dual function is acceptably conservative for that layer. The following sections discuss considerations for the Lower Fox River, following the design flowchart on Figure 3 for evaluating and selecting the design of each of the cap components.

3.2.1 Determine Cap Design Objective

Cap design criteria were discussed in Section 1.4.2.

3.2.2 Bioturbation Component

Aquatic organisms that live in or on bottom sediment can greatly increase the migration of sediment contaminants through bioturbation. The depth to which species will burrow is dependent on the species' behavior and the characteristics of the substrate (e.g., grain size, compaction, and organic content). In general, the depth of bioturbation by marine organisms is greater than that of freshwater organisms. The types of organisms likely to colonize a capped site and the normal behavior of these organisms is generally well known. The technical report, *Subaqueous Cap Design: Selection of Bioturbation Profiles, Depths and Process Rates* (Clarke and Palermo, 2001), in addition to providing information on designing ISCs, also provides many useful references on bioturbation. The USACE has published this document on their website at: http://www.wes.army.mil/el/dots/doer/technote.html.

To provide long-term protection, an isolation cap should be sufficiently thick to prevent direct contact of burrowing organisms with the underlying contaminated sediment, or potentially contaminated subsurface layers of the cap. To design a cap component for this function, the bioturbation potential of local bottom-dwelling organisms should be evaluated. The Lower Fox River is a freshwater system, and the potential depths of bioturbation are limited to the upper few centimeters.

At marine and estuarine cap sites, the bioturbation component of the cap was the primary consideration. At both the Simpson Tacoma cap and the cap at the Convair Lagoon in San Diego, chemical isolation was achieved with a 12- to 18-inch layer of fine sand. The overall design and thickness of the cap was driven by the need to prevent deep-burrowing crustaceans from breaching the cap/sediment interface. At the Simpson cap, this was achieved by a layer of sand with an average thickness of 7 feet. The ISC constructed at Convair Lagoon in San Diego Bay included a gravel layer to resist potential bioturbation by deep-borrowing shrimp known to inhabit the site.

Knowledge of the local conditions and the species likely to colonize the cap is an important consideration in cap design. Deep-burrowing organisms are not likely to be a consideration at the Lower Fox River. A survey of noted aquatic biologists from several research facilities around the Great Lakes was conducted for the EPA ISC guidance document (Palermo et al., 1998b). The surveyed researchers generally agreed that the most likely benthic organisms to colonize a sand cap in the Great Lakes would be chironomids (midges) and oligochaetes (worms). One researcher indicated that spaerids (fingernail clams), trichopteran larvae, and nematodes might also colonize the sand cap. An armored cap would attract a greater diversity of macroinvertebrates than a sand cap, including those that attach to surfaces (including zebra mussels) or inhabit the larger interstitial spaces. As the interstices of the gravel or stone are filled with "new" sediments, the benthos would likely become dominated by oligochaetes and chironomids. Based on these opinions, a minimal component (or thickness) of an ISC constructed with sand or one having an armored surface appears to be needed to accommodate bioturbation at Great Lakes sites. Benthos at such a capped site is likely to be limited to the fine-grained, organic-rich sediments, which may deposit on top of the cap or settle in the interstices of armor stone. The armor layer component of the cap can therefore be considered the component for both physical isolation and bioturbation (see additional discussion below).

3.2.3 Consolidation Component

Fine-grained granular capping materials could undergo consolidation due to self weight. Even if the cap material is not compressible, most contaminated sediment is highly compressible, and will almost always undergo consolidation due to the added weight of capping material or armor stone. Therefore, consolidation must be considered when designing the cap. The thickness of granular cap material should have an allowance for consolidation so that the minimum required cap thickness is maintained following consolidation. Since the cap for the Lower Fox River would be constructed using sand and gravel/stone, evaluation of cap internal consolidation is necessary. The analysis of consolidation of the underlying contaminated sediments must also be conducted as a part of the evaluation of the chemical isolation cap component (see discussion below).

Consolidation of the underlying contaminated sediment will be a factor for the Lower Fox River. The degree of consolidation of the underlying contaminated sediment will provide an indication of the volume of water expelled by the contaminated layer and capping layer due to consolidation. This can be used to estimate the movement of a front of pore water upward into the cap. Such an estimate of the consolidation-driven advection of pore water should be considered in the evaluation of contaminant flux. Methods used to define and quantify consolidation characteristics of sediment and capping materials, such as standard laboratory tests and computerized models, are available (Palermo et al., 1998a, 1998b).

3.2.4 Stabilization/Erosion Protection Component

The cap component for stabilization/erosion protection has a dual function. This component of the cap is intended to stabilize the contaminated sediment being capped, and prevent the sediment from being resuspended and transported off site. The other function of this component is to make the cap itself resistant to external and internal erosion.

External Stability

The potential for erosion depends on stream flow or tidal velocity forces, ice scour, depth, turbulence, wave-induced currents, ship/vessel drafts, engine and propeller types, maneuvering patterns, sediment particle size, and sediment cohesion. Potential for episodic events such as floods, lake storms, ice dams, ship groundings, etc., should be evaluated. For the Lower Fox River, the potential for erosion due to floods is the major consideration for cap design. Ice scour is of concern only for water depths shallower than 3 feet, and habitat constraints and ice scour dictate that the surface of any cap on the Lower Fox River will not be at water depths less than 3 feet. Maintaining a minimum of 3 feet of water depth will also discourage establishment of emergent vegetation which might bioturbate the cap and exacerbate ice scour.

Hydrodynamic modeling conducted to date for the Lower Fox River has indicated that the surface cap layer must be designed as an armor layer to resist erosion. A detailed analysis of the armor layer requirements must be conducted as a part of the cap design. The analysis should be based on an evaluation of a 100-year flood event.

Internal Stability

Internal stability refers to geochemical processes that can create cap breaches. Little is known regarding the impact of gas generation on the effectiveness of a cap. Gas generation is a process related to internal geotechnical stability of the sediments, which has only recently received attention as a cap design consideration. Methane generation in sediments appears to be highly temperature-dependent (Matsumoto et al., 1992). The placement of a sand and gravel/stone cap may tend to isolate the fine-grained contaminated sediment layer from temperature changes, and could therefore reduce the potential for gas generation as compared to the uncapped existing conditions. Potential problems with gas generation that may affect cap design are gas buildup and contaminant migration associated with gas movement upward through the cap.

Gas generation and subsequent buildup may cause disruption of a membrane or low-permeability cap layer. This was illustrated by the displacement of a temporary membrane cap placed by EPA at the Manistique site. A 100-foot by 240-foot high-density polyethylene (HDPE) plastic membrane (40-mil) mat was placed over a hot spot at this site as a temporary control. The mat was weighted on the bottom with Jersey barrier concrete sections attached to the mat with cable and was fitted with 10 gas control valves to relieve gas buildup. An inspection of the mat 12 months after installation found that a number of bubbles had formed under the mat, causing upward displacement of the mat off the bottom as high as 8 feet (Lopata, 1994). Ultimately, this cap was removed and sediments were dredged from this site. In Wisconsin, a capping project at Oxbox Lake in Wausau capped lead-contaminated sediments in the late 1990s. The cap consisted of 2 feet of sand over a geotextile. A unique technical innovation on the project was that the cap materials were placed in the winter on the frozen lake surface and then allowed to settle into place upon ice melt. Results of a recent inspection report found that methane buildup under the geotextile caused part of the cap to surface, appearing as large bubbles at the water surface. This raising, in turn, pulled the geotextile and cap material off of the underlying contaminated sediments (WDNR, 2002c).

Since a granular material (sand) with no membrane or geotextile is anticipated for any Lower Fox River caps, there is no potential for a gas buildup problem, even if gas continues to be generated following cap placement.

Methane generation is common in most systems and has been observed at other capping sites, but has only recently become a consideration for cap design. For example, at one of the oldest and most successful caps, the Simpson-Tacoma site, methane seeps were observed coming out through the cap, and the Washington Department of Ecology required sampling to ensure that this breach did not carry contaminants (Stivers and Sullivan, 1994).

The models now in common use for evaluating cap effectiveness do not consider gas generation as a possible contaminant transport mechanism. As mentioned above, placement of a cap would insulate sediment from temperature increases during summer and would likely reduce the potential for gas generation. Based on these considerations, an increase in cap thickness to account for gas generation should be considered in determining an appropriate factor of safety in the cap design.

3.2.5 Chemical Isolation Component

If a cap has a properly designed physical isolation component, contaminant migration associated with the movement of sediment particles should be controlled. However, the movement of contaminants by advection (flow of pore water) upward into the cap is possible, while movement by molecular diffusion (across a concentration gradient) over long periods is inevitable. Since cap functions related to the quality of sediments in the cap are a goal for the Lower Fox River, an evaluation of contaminant flux and chemical isolation effectiveness of the cap is necessary. Such an analysis will include capping effectiveness testing and modeling.

Diffusion is the process whereby ionic and molecular species in water are transported by random molecular motion from an area associated with high concentrations to an adjacent area associated with a low concentration (Fetter, 1994). Although diffusion is a very slow process, diffusion-driven mass transport will always occur if concentration gradients are present. Consequently, diffusion can transport contaminants through a saturated porous media in the absence of advection. This process will be the principal mechanism for evaluation of cap design for the Lower Fox River from the standpoint of effectiveness for chemical isolation.

Advection refers to the flow of sediment pore water or underlying groundwater. Advection can occur as a result of compression or consolidation of the contaminated sediment layer or other layers of underlying sediment. Advection of pore water due to consolidation would be a finite, short-term phenomenon. Advection can also occur long-term as an essentially continuous process if there is an upward hydraulic gradient due to groundwater flow. Contaminants can be transported by advection as dissolved or particle-bound concentrations (e.g., ligand-sorbed colloids) (EPA, 1995). Available data indicate that continuous groundwater flow may not be a design issue for the Lower Fox River.[1] However, placement of the cap on compressible sediments will result in advection due to consolidation, and this process should be considered in the design.

Even if chemical concentrations are high in the contaminated sediment pore water, a granular cap component can act as both a filter and buffer to chemical migration during advection and diffusion, depending on the physical-chemical properties of the cap. As pore water migrates up into the uncontaminated granular cap material, these cap materials can be expected to fix or retard the transport of contaminants (through sorption, ion exchange, surface complexation, and redox-mediated flocculation) for some time. Therefore, pore water that traveled completely through the full thickness of the cap would theoretically have a reduced contaminant concentration until the filtering and/or buffering capacity or the cap is exhausted. The extent and duration of contaminant fixation or transport in the cap is very much dependent upon the nature of the cap materials. For example, a cap composed of quarry run sand would not be as effective as a naturally occurring sand with an associated fine fraction and organic carbon content.

Some components for cap thickness should not be considered in evaluating long-term flux. For example, the depth of overturning due to bioturbation can be assumed to be a totally mixed layer and will offer no resistance to long-term flux. Erosion components consisting of gravel or stone have little resistance to flux unless fine sediments fill the

[1] While groundwater inflow is not expected to be an issue, it will be necessary during cap design to confirm the absence of sand stringers underneath the cap foundation.

voids. Components for operational considerations, such as an added thickness to ensure uniform placement, would provide long-term resistance to flux. The void ratio or density of the cap layer after consolidation should be used in the flux assessment.

Several testing approaches have been applied to define cap thicknesses and the sediment parameters necessary to model their effectiveness in chemical isolation. Laboratory tests may be used to define sediment-specific and capping material-specific values of diffusion coefficients and partitioning coefficients. Although no standardized laboratory test or procedure has yet been developed to fully account for advective and diffusive processes and their interaction, both diffusion tests and batch and column tests for advective processes have been applied for cap designs. Such tests should be considered for the design phase for the Lower Fox River.

Several numerical models (both analytical and computer models) are available to predict long-term movement of contaminants into or through caps due to advection and diffusion processes. The results generated by such models include flux rates and sediment pore water concentrations as a function of time. These results can be compared to applicable water quality criteria, or interpreted in terms of a mass loss of contaminants as a function of time. The models can evaluate the effectiveness of varying thicknesses of granular cap materials with differing properties (grain size and TOC). The USACE has developed a comprehensive model called RECOVERY/CAP that allows consideration of a varying sediment profile and both advective and diffusive processes. Results from consolidation evaluations can be incorporated in RECOVERY/CAP to consider consolidation-induced advection. This model should be considered for evaluation of the chemical isolation effectiveness as a part of the cap design.

The performance standard of 250 ppb as a limiting PCB concentration in the isolation layer should be used in this analysis.

3.2.6 Operational Components

Even though cap placement methods are available which will minimize sediment resuspension and the mixing of cap material and softer contaminated sediments being capped, all placement methods will result in some degree of mixing. The degree of mixing will depend on the physical nature of the materials and the methods of placement. Mixing is an operational consideration that can be offset by increasing the overall cap design thickness. Penetration into soft, unconsolidated sediments of the initially applied sand cap was observed at the Soda Lake site in Wyoming. Up to 4 inches of the applied sand was found to have mixed with the softer, contaminated sediments before a solid foundation layer was formed that could bear the additional cap material. This is consistent with the modeled findings of Zeman et al. (1992) for the Hamilton Harbor site, who also cited work at the Hiroshima Bay, Japan ISC site where between 2 and 4 inches (5 to 10 cm) had mixed with the underlying contaminated sediments.

Another operational concern is the ability to place a relatively thin cap layer as a uniform layer. Various placement techniques have proven successful in placing layers about 15 to 20 cm (0.5 to 0.75 foot) thick with reasonable assurance (though at increased cost due to increased operational controls). The placement process will likely result in some unevenness of the cap thickness. This unevenness should be considered in calculation of the volume of capping material required.

An additional thickness of sand cap to account for operational considerations such as mixing and uniformity should be added to the design of the cap thickness (Palermo et al., 1998a).

3.2.7 Component Interactions and Overall Cap Thickness

The most conservative design approach for an ISC is to consider components necessary for the basic cap functions independently as described above. Using this approach, components are additive. This approach is most appropriate for caps designed with a single type of granular material, where the total thickness of cap material is the sum of the thicknesses for physical isolation, chemical isolation, and stabilization/erosion protection. Additional amounts of granular material might be added to account for consolidation (discussed below), or for other construction or operational considerations.

The cap components for physical isolation and erosion protection would seem to have the greatest potential for dual function. In the case of an armored layer placed on top of a sand cap and designed to be stable under all but very extreme events, the ability of such a layer as a deterrent to bioturbation might be considered in addition to its erosion protection function.

For the Lower Fox River, the cap design would require components for physical isolation/bioturbation, chemical isolation, and operational considerations. The total thickness of the sand cap layer and armor layer should be determined in the design phase.

For a major Superfund site such as the Lower Fox River, any cap design should incorporate an appropriate factor of safety applied to the cap thickness to account for uncertainty in site conditions, sediment properties, and migration processes. Based on professional judgment of the authors, a factor of 1.5 is considered appropriate. Regulatory or institutional considerations may favor a higher factor.

3.3 Geotechnical Considerations

Geotechnical considerations important to cap design include shear strength of the contaminated sediments (which determine their ability to support a cap), and liquefaction issues for seismically active areas. The Lower Fox River is not in a seismic risk area, so shear strength is the only geotechnical consideration.

Usually, contaminated fine-grained sediment is predominately saturated and therefore has low shear strengths. These materials are generally compressible. Unless appropriate controls are implemented, contaminated sediments can be easily displaced or resuspended during cap placement. Following placement, cap stability and settlement due to consolidation are two additional geotechnical issues.

As with any geotechnical problem of this nature, the shear strength of the underlying sediment will influence its resistance to localized bearing capacity or sliding failures, which could cause localized mixing of capping and contaminated materials. Cap stability immediately after placement is critical, before any excess pore water pressure due to the weight of the cap has dissipated. Usually, gradual placement of capping materials over a large area will reduce the potential for localized failures.

Field monitoring data have shown successful sand cap covering of contaminated sediment with low strength. However, data on the behavior of soft deposits during placement of capping materials is limited. Conventional geotechnical design approaches should therefore be applied with caution. These design approaches could be conservative for conditions normally encountered in cap design. For example, a cap should be built up gradually over the entire area to be capped. This will reduce the potential for mixing and overturning of the contaminated sediment. Similarly, caps with flat transition slopes at the edges should not be subject to a sliding failure normally evaluated by conventional slope stability analysis.

The capping material should be applied slowly and uniformly to avoid problems with bearing capacity or slope failures if the contaminated sediment deposit is soft. Uncontrolled release of a large amount of material or the buildup of a localized mound could cause a bearing capacity failure. If this occurs, cap material will penetrate into the contaminated deposit and could cause contaminated material to resuspend and disperse into the water column.

The sediments of the Lower Fox River are soft and compressible, but no more so than other sediments which have been successfully capped. Methods for cap placement should be considered to gradually build up the sand cap thickness and so minimize sediment and cap mixing and minimize potential for bearing type failures. Once the sand cap component is in place in a given working OU or area, the placement of armor stone can proceed using conventional placement methods.

3.4 Cap Construction

3.4.1 ISC Construction and Placement Methods

A variety of equipment types and placement methods have been used for capping projects. This has included the use of hopper barges at larger, open-water sites, and both hydraulic and mechanical systems for placement at nearshore or shallow-water sites. Some of these methods are shown and described on Figures 4 through 11.

The use of granular capping materials (sediment and soil), geosynthetic fabrics, and armored materials are all ISC considerations discussed in this section. Important considerations in selection of placement methods include the need for controlled, accurate placement of capping materials. Slow, uniform application that allows the capping material to accumulate in layers is often necessary to avoid displacement of or mixing with the underlying contaminated sediment. This can further result in the resuspension of contaminated material into the water column.

Granular cap material can be handled and placed in a number of ways. Mechanically dredged materials and soils excavated from an upland site or quarry have relatively little free water. These materials can be handled mechanically in a dry state until released into the water over the contaminated site. Mechanical methods (such as clamshells or release from a barge) shown on Figures 4 and 5 rely on gravitational settling of cap materials in the water column, and could be limited by operational depths in their application. Granular cap materials can also be entrained in a water slurry and carried to the contaminated site wet, where they are discharged into the water column at the surface or at depth (Figures 6 through 9). These hydraulic methods offer the potential for a more precise placement, although the energy required for slurry transport could require dissipation to prevent resuspension of contaminated sediment. Armor layer materials can be placed from barges or from the shoreline using conventional equipment, such as clamshells (Figure 10). Placement by mechanical buckets has also been successful at some sites (Figure 11).

3.4.2 Availability of Materials and Equipment

The local availability of sediment, soil, or other granular capping material can have a significant impact on ISC cost and implementation. Capping materials will generally represent the largest single item in the overall project cost. The selection of cap materials (or use of more than one) will be determined by the availability of materials that can meet the RAOs, their cost, and product quality control. Sources of granular materials should be carefully considered. Washed or processed sand would contain little or no organic carbon and would therefore not provide good contaminant isolation. As a result, the use of natural sandy sediment would be preferable for caps. Materials such as geotextiles or armor stone can generally be obtained from commercial sources.

FIGURE 4 PLACEMENT OF THE ISC AT THE WEST EAGLE HARBOR OPERABLE UNIT, BAINBRIDGE ISLAND, WASHINGTON

A

B

C

Placement sand was obtained from routine navigation dredging in the Snohomish River, placed on a spilt-hull barge (A), which was then used to place most of the cap. In shallower areas, the weight of impact from the sand caused a displacement of creosote into the surface water. In order to achieve a softer placement of material, sand was placed on a flat barge and sprayed off the barge with a fire hose while the barge was pushed around the site by the tug (photos courtesy of USACE).

FIGURE 5 HOPPER DREDGE PLACEMENT AT THE DENNY WAY COMBINED STORMWATER OVERFLOW

A

B

Sediments contaminated with metals, polynuclear aromatic hydrocarbons (PAHs), and PCBs below the Denny Way combined sewer overflow in Seattle, Washington were capped in conjunction with a source control program in the 1980s. Contaminated sediments were capped using a partially opened split-hull bottom-dump barge that was pushed laterally across the site. The cap consisted of approximately 5,000 cubic meters of uniformly graded sand (mean diameter 0.4 mm) spread to a thickness within a range of approximately 60 to 90 cm (Sumeri, 1991) (photos courtesy of USACE).

FIGURE 6 HYDRAULIC PLACEMENT AT THE ST. PAUL WATERWAY, TACOMA, WASHINGTON CAP SITE

A

B

The dredged sand was piped to the site and discharged through a diffuser box that was fitted with baffles (A, B). The dredged material comprised approximately 85 to 95 percent medium sand, which included between 2 and 6 percent clays. Approximately 150,000 cubic meters of clean sand were spread over 6.9 hectares. The passes of the spreader barge included one-third overlap during placement to ensure adequate coverage. When completed, the cap ranged from between 0.6 and 3.7 meters in thickness (Sumeri, 1989) (photos courtesy of USACE).

FIGURE 7 HYDRAULIC PLACEMENT AT SODA LAKE, WYOMING

A 

B 

C 

D 

E 

F 

The Soda Lake, Wyoming pilot project placed up to 3 feet of sand over very soft, unconsolidated refinery residuals mixed with sediments. A fine sand was mined on site (A), and conveyed (B) to a blending tank where they were mixed with water to form a 30 percent slurry by volume. The slurry was then pumped using two 175-horsepower centrifugal pumps in series through 4-inch pipe (D) to the spreader barge (E) where it was distributed using a 8-foot-wide diffuser box. The pipeline discharge entered the diffuser box spraying the slurry upward against a baffled surface. This surface distributed the slurry in a lateral fashion less than 1 foot above the water column and promoted a uniform material distribution. The capping material then hit the water column, lost its kinetic energy, and fell vertically onto the bottom sediment. The reduction in slurry velocity resulting from contact with the diffuser plate minimized any potential for erosion of in-place material. The selected sand layer (lift) applied was 1.5 inches per pass to minimize disturbance of bottom sediment and allow time for increased sediment pore pressures to equilibrate. Accumulating cap thickness was monitored during placement using both lead lines and a fathometer. In shallower areas, the cap was placed using an aerial disbursement method (F).

FIGURE 8 DRY CAP PLACEMENT AT THE PINE STREET CANAL DEMONSTRATION PROJECT, VERMONT

A

B

C

A test capping project was undertaken at the Pine Street Canal Superfund Site in Burlington, Vermont. The site is located next to a former manufactured gas plant, where the Consent Decree calls for construction of an ISC in the canal to prevent exposure to aquatic life. The initial demonstration project placed up to 3 feet of sand using a dry-sand placement system mounted on a 16- by 40-foot barge with a shallow (2- to 3-foot) draft. A sand diffuser, consisting of a series of tremies, is attached to a feed hopper (A). A front-end loader is used to transport sand from the barge to the hopper. Sand from the hopper is distributed to the tubes via a rotating paddle located between the hopper and the tubes. This system, which is similar to that used at the Hamilton Harbor, Ontario capping site, uses a series of tremie tubes arrayed across an approximately 10-foot span (B). The barge is pulled along the installation path via a cable-and-pulley system (C). At this trial site, the diffuser was set to deliver either 0.5- or 0.75-foot lifts (photos courtesy of The Johnson Company).

FIGURE 9 HYDRAULIC PLACEMENT OF CAP MATERIAL IN THE NETHERLANDS

This automated hydraulic capping barge has been developed in the Netherlands for the placement of thin layers of sand for capping of contaminated sediments or as a foundation layer on very soft sediments. The system, developed by the Dutch dredging firm Royal Boskalis Westminster, in alliance with Bean Environmental LLC of New Orleans, Louisiana, consists of a spreader barge connected to a slurry pump, which is loaded by either a dredge or hopper. The production of the solids is measured in real time. The winch system of the capping barge is a fully automated, dynamic tracking system and follows parallel lanes. The hauling speed of the barge is automatically steered by the quantity of capping material discharged, the lane width and the required layer thickness of the cap. The system was used in the construction of foundation layers at the Derde Merwede Haven and Ketelmeer confined disposal facilities, and for the placement of foundation layers at the Ijburg residential island construction in Amsterdam, where very thin layers of sand were required to be placed on an extremely soft surface sediment. All of these sites are located in the Netherlands. The automated capping barge achieves production rates in excess of 1,500 cubic meters per hour, and provides material distribution of clean, poorly graded imported sand in uniform 0.3- to 0.7-meter layer thickness by means of this sophisticated slurry control and barge advance system (photo courtesy of Bean Environmental LLC).

FIGURE 10 MECHANICAL PLACEMENT AT THE SHEBOYGAN DEMONSTRATION PROJECT

The demonstration project at the Sheboygan River, Wisconsin, placed a composite cap over PCB-contaminated sediments. The project first set a 100-micron geotextile fabric placed directly over the soft sediments (A), followed by a 12-inch layer of run-of-bank material (B), a second geotextile fabric layer that was secured with 3-foot by 3-foot stone-filled gabions at the perimeter, and then finished with a 12-inch-thick armor layer of 4 to 12 inches of cobble (C).

FIGURE 11 MECHANICAL PLACEMENT AT WARD COVE, ALASKA

A

B

Ward Cove near Ketchikan, Alaska was capped as part of a CERCLA action in 2000–2001. Contaminants at Ward Cove were byproducts of the paper waste product that was released during wastewater discharge. The EPA wanted to evaluate a thin-layer capping (6 inches) alternative as a method for enhancing natural recovery and as a habitat improvement action. The underlying material was very soft, unconsolidated sediment with low *in-situ* shear strength and high water content. Placement was with an 8.5-cubic-yard (cy) bucket that was welded to hold an exact amount of material that was equivalent to a 6-inch placement over the 300-square-foot arc across which the bucket was swung. The material was released below the water surface within 10 to 20 feet of the bottom. Sediment grain size for the cap was a fine to medium sand that was less than 5 percent non-plastic silt. The contract was written so that the contractor was paid by the amount of material placed. Gravity probes were used to confirm that the project was successful; a final cap thickness of 6 to 9 inches was achieved (photos courtesy of Greg Hartman).

3.4.3 Contaminant Releases During Construction

During cap placement, resuspension, volatilization, or other movement of chemical contaminants can occur. The potential short-term risk to the community, workers, or environment during cap placement should therefore be evaluated. Even though there are no standardized methods to predict the degree of contaminated sediment resuspension resulting from cap placement, field data provide some insight on this process. EPA has conducted monitoring of capping-induced resuspension for projects at Eagle Harbor and Boston Harbor (Magar et al., 2002). Capping resuspension was low for both of these sites and decreased as capping operations continued. Similar results were also found for capping resuspension monitored for a large-scale capping field pilot study at the Palos Verdes site (Palermo et al., 2001; McDowell et al., 2001), where contaminant concentrations quickly returned to background levels. Extensive water quality monitoring of capping-induced resuspension conducted for the Soda Lake project (ThermoRetec, 2001) found no detections of site-related petroleum hydrocarbons. The overall results from these studies indicate that levels of sediment resuspension due to well-managed capping operations were acceptable and comparable to those for well-managed environmental removal projects.

Measures to reduce the potential for resuspension, volatilization, or other contaminant movement should include selection of cap materials, placement equipment, and methods designed to spread the capping material over the site gradually. For the Eagle Harbor project, cap material was hydraulically washed off a barge. A manifold arrangement for placement of cap material slurry was used at a capping project at Hamilton Harbor in Canada. At both the Simpson Tacoma project and Soda Lake, a horizontal auger dredge was used as a cap material placement device. These and other projects illustrate the range of possible approaches that have been successfully used to place caps in a gradual manner to minimize potential for resuspension and displacement of contaminated sediments.

The potential short-term risk to the community, workers, or environment during cap placement should be evaluated. Measures to reduce the potential for resuspension, volatilization, or other contaminant movement should include selection of cap materials, placement equipment, and methods designed to spread the capping material over the site gradually. Selection of the proper construction techniques will allow the cap to be gradually built up without the potential for geotechnical instability (bearing or slope failure) or excessive disturbance. In addition, silt curtains and other barriers can be used to prevent or minimize contaminant migration. In extremely contaminated areas or at shallow sites, sheet pile cofferdams can be used to prevent contaminant migration from the construction site.

4 MONITORING CONSIDERATIONS

A monitoring program should be required as a part of any capping project design. The main objectives of monitoring for ISC would normally be to ensure that the cap is placed as intended and that the cap is performing the basic functions (physical isolation, sediment stabilization and chemical isolation) as required to meet the remedial objectives. Specific items or processes that may be monitored include cap integrity, thickness, and consolidation, the need for cap nourishment, benthic recolonization, and chemical migration potential.

Intensive monitoring is necessary at capping sites during and immediately after construction, followed by long-term monitoring at less frequent intervals. In all cases, the objectives of the monitoring effort and any management or additional remedial actions to be considered as a result of the monitoring should be clearly defined as a part of the overall project design. The cost and effort involved in long-term monitoring and potential management actions should be evaluated as part of the initial FS.

Monitoring programs for Simpson, Eagle Harbor, Soda Lake, and other projects have included components for resuspension and cap integrity during construction as well as components for long-term cap effectiveness. Plume monitoring with instruments as well as discrete samples for contaminant concentrations are the usual approaches for resuspension monitoring. Pre- and post-bathymetric surveys, along with consolidation measurements, help evaluate whether cap thickness design objectives are achieved. Cores taken through the cap are the most frequent tools used to determine cap integrity during and immediately following construction as well as at longer time intervals for purposes of long-term effectiveness. Samples from the cores are analyzed for both physical parameters as well as sediment and/or pore water chemistry.

For the Lower Fox River, it is especially important that the performance standard of 0.25 ppm in the upper layer of the cap be confirmed by monitoring.

Any construction monitoring to determine if this standard is met needs to occur PRIOR to placement of the armor layer. For long-term monitoring for effectiveness, sediment samples should be taken in the lower portions of the cap profile in addition to the upper biologically active zone. This will determine if any contamination in the cap is due to cap performance issues (migration from below) or recontamination from above.

5 INSTITUTIONAL AND REGULATORY CONSIDERATIONS

There are very few federal or state laws that pertain specifically to ISCs. While various chapters of the Wisconsin Administrative Code contain technical or administrative requirements for the management of waste material and contaminated media, there are no regulations that are specifically directed to the planning, permitting, design, construction, or maintenance of ISCs.

On the other hand, there are certain compelling interests in managing contaminated sediment that are parallel to those that arise when managing wastes and contaminated media. In a certain sense, a sediment cap, as a means of protecting human health and the environment, is analogous to a landfill cover at a Subtitle D facility or a soil performance standard at a spill site. Like these other control mechanisms, a cap over contaminated sediment can reduce the likelihood of migration, the opportunity for contact and biological uptake, or a combination of both. As with some land-based containment systems, the sediment cap uses earthen materials to provide control and physical separation. When correctly designed, properly constructed and well maintained, it can be an alternative method for achieving risk-based goals for reducing human and aquatic exposures.

A soil, aggregate, or multimedia cap that is used to contain contaminated sediment might therefore be subject to the same kinds of objectives as for other regulated materials. These include the following:

- The selection of the type of cap should be based on providing an appropriate physical barrier to limit contact with or migration of contaminants (or both).
- The design of the cap should provide for resistance to erosion, decay, or incidental penetration.
- The cap should be subject to periodic inspections and maintenance to insure that it accomplishes its design objectives over its intended life.
- Financial assurance should be established to provide for this post-construction, long-term monitoring, and maintenance.
- The cap must meet the substantive requirements of both state and federal law.
- The planning, design, construction, and monitoring phase of the project should be subject to state review at certain key milestones.

The fulfillment of objectives like these is the basis for various state regulations. Certain rules provide specific technical requirements for environmental facilities (e.g. solid waste landfills, hazardous waste incinerators, wastewater treatment plants). Other rules require the use of general evaluation methods and broad mandates for accomplishing protection (e.g., the NR 700 series of rules for remedial actions).

In addition, since the use of an ISC involves construction within navigable waters, there are additional considerations beyond those that affect land-based remediation. These are discussed specifically in the following subsection. Federal rules, other state rules, institutional considerations, and recent practices are discussed in subsequent subsections.

5.1 CONSTRUCTION WITHIN NAVIGABLE WATERS OF WISCONSIN

Wisconsin Statutes Chapter 30 prohibits the deposition of materials except into structures that are permitted or authorized under statute or other legislative means (WDNR, 1998). It also requires the issuance of permits for the construction of any structure on the bed of navigable water. The authorization and permitting of a project is, in turn, affected by the ownership of the bed. In Wisconsin, this varies according to the type of water body, as follows:

- For natural, navigable lakes the state owns the bed.
- For rivers, upland owners have riparian rights that extend to the center of the stream. (This includes "man-made" lakes or reservoirs created by the damming of a river. Riparian ownership is determined as though the previous stream still remains.)

As a result of these differences, deposits on the bed of navigable waters have historically been authorized under by one of four means (WDNR, 1998):

1. **Legislative Authorization:** For a river, the legislature can authorize a project with riparian owners as applicants or co-applicants. (In this context, it is important to note that riparian owners may separate the ownership or the riverbed from the ownership of the adjacent land, and riparian rights may be sold or leased.) In doing so, however, the project must be shown to be consistent with the public trust doctrine.

2. **Lakebed Grants:** For lakes, a "lakebed grant" from the legislature can remove the prohibition on deposits of material. The structure itself would still be subject to all approvals and permits required to protect the water quality of the surrounding water body.

3. **Bulkhead Lines:** Bulkhead lines can be used, but are required to conform as nearly as practicable to existing shores. Therefore, they would probably not be applicable to a broad area of ISC placement.

4. **Leases:** The Commission of Public Lands may lease the rights to the beds of lakes to a municipality for the purpose of improving navigation or harbors. The WDNR must establish that such a lease would be in the public interest, and they may include conditions of use and operation.

These considerations indicate that an RP who wishes to construct a sediment cap is not free to do so without consideration of riparian rights and without a means of authorization from the State. From the outset, there would be a commercial aspect to this process, in that the RP may need to negotiate with and provide compensation to private riparian owners. Equally important, however, would be the demonstration that the proposed ISC is an improvement allowable and envisioned under state law and that if authorization is provided, the state would continue to maintain its obligation to the public trust. Further, once the appropriate means of authorizing the project is established and implemented, the regulatory permitting process will add requirements that are necessary for the protection of the aquatic resource.

The applicability of Chapter 30 requirements and the use of lakebed grants for sediment caps is just beginning to be explored. While the WDNR has started to make determinations on which authorities (e.g., legislative authorization, lakebed grants, etc.) might be used on certain water bodies, it does not appear that a sediment capping project has yet moved fully through the process. Final determinations are likely to require considerable additional work and subsequent interpretations. In addition, obtaining a lease or lakebed grant is likely to result in additional financial encumbrances not otherwise accounted for.

5.2 OTHER WISCONSIN REGULATIONS

Beyond the laws that specifically affect the ability to construct a project within navigable waters, there are a range of other possible state regulations that may affect the planning, design, construction, or maintenance of an ISC remedy. Table 4 contains information on state regulatory requirements. These regulations, which cover such things as capping of upland disposal sites and other aspects of remedial activities, are not directly applicable to an ISC. They do, however, provide some general direction and they suggest how relevant state regulations may be considered for an ISC project.

Each of these items is characterized (for informational purposes) as being either “procedural” or “technical.” A procedural item, for example, could be the submittal of a work plan or other document. A “technical” requirement might specify a design feature, material of construction, or construction method.

The “procedural” aspects of the NR 700 series would probably be relevant to most ISC projects because they are, by definition, intended to be generic to a wide range of remedies. Technical items developed under other regulatory programs may have less relevance because they are usually facility-specific (such as the thickness of the vegetative layer for a landfill cover).

5.3 FEDERAL REQUIREMENTS

Section 10 of the Rivers and Harbors Act of 1899 (22 CFR 403) permitting is required for any construction that would impact the course, capacity, or condition of navigable waters of the United States (Palermo et al., 1998b). Any cap would be considered as an obstruction to navigation. For the Lower Fox River, the federal navigation channel runs the length of the River up to the Menasha Locks to Lake Winnebago. If a cap footprint were proposed within an authorized federal navigation channel, congressional action would be required to de-authorize the project or modify the authority.

TABLE 4 WISCONSIN "ACTION-SPECIFIC" REGULATIONS THAT MAY BE RELEVANT TO SEDIMENT CAPPING PROJECTS

Citation from Wisconsin Administrative Code	Is the Regulation Procedural or Technical?	Specific Item	Is There a Parallel Procedural or Technical Element in a Sediment Capping Project?	Comment
Chapter NR 504 – Landfill Location, Performance, Design, and Construction Criteria				
504.07	Technical	This paragraph establishes minimum design requirements for a solid waste landfill cover system. Includes design objectives, materials specifications, and thickness of layers.	Yes. The sediment cap is analogous to a landfill cover. It is subject to some of the same kinds of stability and long-term maintenance concerns which have been addressed for landfill covers via this paragraph.	The NR 500 series of regulations are not applicable to sediment capping. Further, the specific design elements contained in this paragraph are not relevant to a sediment cap. However, some of the underlying design objectives for landfill covers that are stated in 504.07(1)(a) would be relevant and appropriate. These include: • "Reduce…maintenance by stabilizing the final surface…" and • "Account for differential settlement and other stresses on the capping layer…" Just like in a landfill cover project, these objectives would form the basis for design of the sediment cap (i.e., the selection of materials and thickness that would resist erosive forces in the River and which could be adequately supported by the sediment bed).
Chapter NR 506 – Landfill Operational Criteria				
506.08	Procedural and Technical	Establishes general closure requirements for solid waste landfills, as well as specific requirements for facilities that accepted municipal solid waste up to certain cutoff dates.	Yes. The sediment cap could be viewed as the closure mechanism for a historic disposal location.	Not applicable. Because they are focused on a particular kind of solid waste facility, the specific content of this paragraph is not as relevant to a sediment cap as other parts of the NR 500 code might be.

TABLE 4 WISCONSIN "ACTION-SPECIFIC" REGULATIONS THAT MAY BE RELEVANT TO SEDIMENT CAPPING PROJECTS

Citation from Wisconsin Administrative Code	Is the Regulation Procedural or Technical?	Specific Item	Is There a Parallel Procedural or Technical Element in a Sediment Capping Project?	Comment
Chapter NR 514 – Plan of Operation and Closure Plan for Landfills				
514.08	Procedural	Requires the submittal of a closure plan for solid waste disposal facilities that do not have an approved plan of operation, or which are required to develop a closure plan as remediation for surface water contamination.	Yes. The sediment cap is, in part, a response action to an instance of surface water contamination.	Appears relevant. Because it is only a procedural requirement, though, it may not be appropriate if another relevant regulation is invoked (such as NR 724.09, 724.11, or 724.13) that requires equivalent information in a more focused document.
Chapter NR 516 – Landfill Construction Documentation				
516.04	Procedural	Describes the procedures for construction quality assurance and documentation reporting for construction at solid waste landfills.	Yes. The construction of the sediment cap is analogous to the construction of a landfill cover and would be subject to the same kinds of construction quality assurance and documentation.	Appears relevant. This paragraph merely sets forth a procedural task that is already largely consistent with conventional engineering practice. It would only be viewed as not appropriate if some other relevant regulation is invoked (such as NR 724.15) which is more targeted to remediation work.
516.06	Procedural and Technical	This paragraph describes more of the substantive requirements for closure documentation and reporting, such as the grid interval for determining final grades and the content of documentation drawings.	Yes. The types of documentation activities anticipated by this paragraph would also occur in a sediment capping project.	Some of the general requirements would be relevant. It would only be viewed as not appropriate if some other relevant regulation is invoked (such as NR 724.15) which is more targeted to remediation work.

TABLE 4 WISCONSIN "ACTION-SPECIFIC" REGULATIONS THAT MAY BE RELEVANT TO SEDIMENT CAPPING PROJECTS

Citation from Wisconsin Administrative Code	Is the Regulation Procedural or Technical?	Specific Item	Is There a Parallel Procedural or Technical Element in a Sediment Capping Project?	Comment
516.07	Technical	Contains the required frequency for materials testing during construction.	Yes. Some of the earthen materials used in a landfill cover may also be used in a sediment cap.	Some of the requirements for testing of specific materials (such as sand or small aggregate) may be relevant and appropriate. (Note that as a practical matter and so that the total number of samples is not unreasonable, the actual frequency of testing may be modified if very large volumes of cap material are required.)
Chapter NR 520 – Solid Waste Management Fees and Financial Responsibility Requirements				
520.05	Procedural	This paragraph identifies three types of site activity for which owners of solid waste facilities must establish financial responsibility: • Closure; • Long-term care; and • Remedial action.	Yes. Construction of a sediment cap constitutes a closure action, and long-term care (maintenance) is necessary.	Although a sediment cap is not one of the specific facilities identified in NR 520, the objective of establishing responsibility for future costs is relevant.
520.06	Procedural	This paragraph identifies seven different financial instruments by which owners can establish financial responsibility.		
520.07 and 520.08	Technical	Identifies the types of costs and methods of estimating which must be included within the categories of closure, long-term care and remedial action.		

TABLE 4 WISCONSIN "ACTION-SPECIFIC" REGULATIONS THAT MAY BE RELEVANT TO SEDIMENT CAPPING PROJECTS

Citation from Wisconsin Administrative Code	Is the Regulation Procedural or Technical?	Specific Item	Is There a Parallel Procedural or Technical Element in a Sediment Capping Project?	Comment
Chapter NR720 – Soil Cleanup Standards				
Note: The elements within this chapter that describe the process for calculating soil cleanup standards are not included in this analysis. For the Lower Fox River and Green Bay, the action level for contaminated sediments would be based on site-specific risk calculations and risk management decision.				
720.19(2)	Technical	Allows for the use of a soil performance standard when contaminants are left in place (in excess of what would otherwise be a residual contaminant level). If used, the soil performance standard must then be operated and maintained in accordance with NR 722 and NR 724 (see below).	Yes. A "soil performance standard" may consist of an engineering control, such as a physical barrier, to limit exposure or contact with residual contaminants. In this sense, a sediment cap is analogous to a cover system, pavement or other containment structure.	May be relevant. The rule anticipates that a soil performance standard would achieve one of more of the following: 1. Isolate residual contaminants from direct contact (by a physical barrier); 2. Limit infiltration and subsequent migration via groundwater (via a low-permeability barrier); or 3. Otherwise stabilize the soil while natural degradation reduces the contaminant concentration to within acceptable levels. Goals Nos. 1 and 3, for example, could be similar to those sought when selecting a sediment cap as a remedy.
Chapter NR 722 – Standards for Selecting Remedial Action				
722.09(2)(c)(3)	Procedural	This paragraph requires that, for sites "in surface water bodies or wetlands," active remedial actions be taken to preclude any exceedance of water quality criteria in Chapters NR 102 to NR 106.	Yes. In some cases, the goal of the sediment cap may be to prevent resuspension or dissolution of contaminants that might lead to an exceedance of water quality criteria in the overlying water column.	Could be relevant to the evaluation and selection of a sediment cap.

TABLE 4 WISCONSIN "ACTION-SPECIFIC" REGULATIONS THAT MAY BE RELEVANT TO SEDIMENT CAPPING PROJECTS

Citation from Wisconsin Administrative Code	Is the Regulation Procedural or Technical?	Specific Item	Is There a Parallel Procedural or Technical Element in a Sediment Capping Project?	Comment
722.09(3)	Procedural	This paragraph introduces the concept of a performance-based standard in lieu of a numeric cleanup standard.	Yes. A sediment cap is a "performance-based" remedial action (as compared to, say, an action that removes contaminants down to a risk-based, numeric standard).	Appears relevant.
722.13	Procedural	This paragraph contains the requirements for the submittal of a Remedial Action Options Report (RAOR).	Yes. Presumably, the selection of a sediment cap would generally be made after a review of remedial options and that process would generally be documented in a report of this type.	Appears relevant, unless the project is organized under some other regulatory authority (such as CERCLA) with its own document submittal requirements. The analog to a ROAR would probably be an FS.
Chapter NR 724 – Remedial and Interim Action, Design, Implementation, Operation, Maintenance and Monitoring Requirements				
724.09	Procedural	Describes the required contents for a "design report" for the selected remedial action at sites regulated under Section 292.11 or 292.31. (This also applies to sites referenced in 724.02, which in turn specifically includes "on-site engineering controls or barriers…")	Yes. Such a report would most likely be produced for any capping project once the concept for the remedy was established and approved.	NR 724 appears relevant because of the broad definition of regulated sites and the latitude that WDNR has in selecting a regulatory authority (NR 724.02(2)). The regulation sets forth a procedural task that is already largely consistent with good and conventional engineering practice. On the other hand, the regulation may not be appropriate if the site is being managed under the NCP where the administrative requirements for document submittal are generally more comprehensive.

TABLE 4 WISCONSIN "ACTION-SPECIFIC" REGULATIONS THAT MAY BE RELEVANT TO SEDIMENT CAPPING PROJECTS

Citation from Wisconsin Administrative Code	Is the Regulation Procedural or Technical?	Specific Item	Is There a Parallel Procedural or Technical Element in a Sediment Capping Project?	Comment
724.11	Procedural	Includes the substantive requirements for the production and submittal of construction-level plans (drawings) and specifications.	Yes. These documents would routinely be produced prior to construction of the project.	Appears relevant. The regulation sets forth a procedural task that is already largely consistent with conventional engineering practice. May also be appropriate if more comprehensive NCP protocols are not being followed.
724.13, especially (2)	Procedural	Includes the substantive requirements for the production and submittal of an "operation and maintenance plan." It includes the consideration of long-term monitoring, required under 724.17 (see below).	Yes. Such a plan could also be produced to describe the post-construction inspection, testing, and maintenance of the cap.	
724.15	Procedural	Includes the substantive requirements for the production and submittal of a "construction documentation report."	Yes. This kind of report would routinely be produced to document the construction of the cap.	
724.17	Procedural	Includes the substantive requirements for the parameters, frequency, and reporting of a long-term monitoring program. This paragraph also allows for a 5-year review by WDNR.	Perhaps. Such a program would be an element of the operation and maintenance plan. In addition to monitoring of the physical nature of the cap, it might also incorporate ongoing sediment chemical monitoring if long-term natural degradation of contaminants is an expectation of the remedy.	Parts of the paragraph appear relevant. Certain elements which anticipate chemical monitoring and data reporting may not be relevant. May also be appropriate if more comprehensive NCP protocols are not being followed.

While daunting, such relief from federal requirements is not unachievable. For example, capping was conducted on a portion of the federal navigation channel at the Manistique Harbor Superfund site in Michigan. That action was approved in Congress. For the Lower Fox River, Congress has approved the transfer of authority for the existing system of locks from the USACE to the state. In this case, the federal government will also relinquish control of the channel. In turn, the state has indicated that it will maintain a navigational depth of at least 4 feet. (Note that, while authorized, this transfer has not yet occurred.) If this is accomplished, a grant or release will then be required from the State Legislature. Until that time, however, the state's current interpretation is that "you can't fill in a federal channel."

5.4 INSTITUTIONAL CONTROLS

In addition to the affects of specific state and federal laws and regulations, a series of institutional considerations will also affect an ISC project. These may include restrictions on the bed where the project is constructed (analogous to traditional "deed restrictions" for a land-based project), as well as possible "water use" restrictions that would affect the resource overlying the bed.

Whether a cap is constructed over a leased bed from a riparian owner, or as part of a lakebed grant by the legislature, it will be necessary to set permanent restrictions on future development. This may include restrictions on setting utility or cable corridors, construction of fixed-post docks, or any other construction activity that would otherwise disturb the integrity of the cap. Water use restrictions might include limits on anchoring or propeller and keel impacts.

An assessment of the need for and reliability of such institutional controls should be part of an evaluation of the long-term effectiveness and permanence of a capping remedy. The ability to devise appropriate controls, educate the public regarding the need for controls, and enforce the controls should also be considered.

An inherent assumption in the cap designs discussed herein is that the location of the ISC will remain permanently submerged. On the Lower Fox River, this in turn, requires a commitment to the maintenance of the system of dams and locks on the River. There are already a number of compelling reasons for doing so (such as providing a lamprey barrier, hydropower capability, water supplies, and recreational use), but the use of ISC as a long-term remedial action will add to this list.

This range of institutional controls should be identified and memorialized as part of a detailed, long-term maintenance plan (LTMP). More broadly, the LTMP would include such elements as the following:

- Identification of failure modes that could result from the loss of institutional controls (degradation from propeller wash, etc.);

- Identification of failure modes the could result from natural causes (excessive ice scour, extreme flood events, etc.);

- Description of maintenance procedures or restoration activities needed for each type of failure;

- A schedule of routine inspections and sampling; and

- A means of identifying if the ISC has been affected by contaminants reloading the River system.

When routine inspections and sampling indicate a potential problem, actions will be required to physically repair the cap. A more complete assessment will be required to fully evaluate the type and severity of the failure and potential corrective measures. There are several ways a cap may fail. The more benign would be contaminant flux is greater than estimated and the design concentration has been exceeded. Catastrophic failure could occur during placement (due to shear failure) or scouring due to flood, ice, or propeller wash. Once this is determined, the type of maintenance can be specified. Maintenance could range from full cap replacement to placing additional cap materials or armor over the failed area.

5.5 Fiduciary Responsibility

Fiduciary responsibilities for an ISC are equivalent to those associated with any upland landfill or soil cap; the RP retains the long-term liability for the cap in perpetuity. This is also consistent with soil caps at brownfield sites, where there is no transfer of liability for the site. An additional fiduciary responsibility that will need to be considered for an ISC at the Lower Fox River includes the long-term maintenance of dams on the River, and/or the potential for management of remnant deposits in the event of dam failure or removal.

5.6 Recent Projects within Wisconsin

This section describes how ISC projects have been approved, designed, and/or implemented in Wisconsin. Where appropriate, references are made to some of the regulations described above.

While there have been a large number of capping projects addressing soils and waste materials within the state, only a very limited number of ISCs have been built. Two examples include the Sheboygan River and Harbor, a National Priorities List (NPL) site in eastern Wisconsin, and the Wausau Steel site, in north central Wisconsin.

At Sheboygan, PCBs were (and are) the constituent of concern. Sediment “armoring” was proposed as a pilot study in approximately 1989 and constructed in 1990, as part of the Alternative-Specific Remedial Investigation (ASRI) for the site. The objectives of the pilot study were as follows (Blasland, 1989):

- Demonstrate the constructability of the technology;
- Evaluate the effectiveness of reducing water column PCBs;
- Evaluate the effectiveness of reducing the bioaccumulation potential of PCBs;
- Develop engineering data for future projects; and
- Assess the impact on in-situ biodegradation of PCBs.

From an engineering perspective, the Sheboygan cap was designed for structural integrity. It is not clear how the above-stated goals impacted the specific design chosen. In total, it consisted of the following layers and materials:

- Geotextile fabric (placed directly on the soft sediments);
- 6-inch minimum run-of-bank aggregate material;
- Geotextile fabric;
- 6 inches of cobble; and
- The perimeter of the geotextiles was anchored with 3-foot by 3-foot stone-filled gabions.

The Sheboygan River project has followed federal National Contingency Plan (NCP) protocols. Both EPA and WDNR provided review of and comments on the technical aspects of the work. The project pre-dated the Wisconsin NR 700 series of rules and there were no specific technical regulations available or cited that covered the planning, design, construction, or operations of the sediment cap. WDNR commented at the time that, in general, the technology should be used sparingly and only for sediments at point bar locations with "low" PCB concentrations (WDNR, 1989). Specific contaminant levels were not stated.

Since it was constructed as a pilot project, the burden of performance monitoring would have fallen on the RP. Apparently, an agreement with the RP on a suitable monitoring program was never reached (Janisch, 2002). As a result, there appears to have been only limited monitoring or studies targeted towards determining the success with which the above-stated goals have been met. In a general sense, the performance has not been viewed favorably. Deficiencies observed by WDNR personnel over time have included the following (Weitland, 2002):

- From a biological standpoint, the technology was felt to be inappropriate.
- PCB concentrations in downstream sediment traps increased (although it is not certain that these PCBs emanate from the armored locations).
- There has been visible damage to the gabions resulting from subsequent storm events and/or ice action.

As early as 1997, after a technical review of the original FS for the permanent site remedy, the Lake Michigan Federation recommended that the removal of the armoring be included as a component of some of the long-term alternatives for the site (BT2, 1997). In fact, EPA's Record of Decision for the final site remedy now calls for it to be removed.

A second sediment capping project of interest has been the Wausau Steel project in Wausau (also referred to as the "Oxbow Lake" site on the Big Rib River). The contaminants of concern were zinc and lead, and a cap was proposed in the late 1990s as a means of addressing both in-place sediments and on-site soils. The Remediation and Redevelopment Bureau and the department's sediment team jointly reviewed the project. Chapter 30 permitting (referenced above) was administered through the department's Water Regulation and Zoning group, as for any construction in a navigable waterway.

The cap consisted of 2 feet of sand over a geotextile. The technical innovation on the project was that the cap materials were placed in the winter on the frozen lake surface and then allowed to settle into place upon ice melt.

The RP, through a consent order, is required to perform monitoring and maintenance for a 5-year period and to submit annual reports. To date, much of the cap has survived. However, within the first few years following construction, WDNR personnel observed that, in places, tears and holes had occurred, and some of it was pulling away from the shoreline. Erosion has occurred from storm events, and in at least two areas, gas generation from beneath the geotextile has caused it to "bubble." It had pushed through the sand layer and was exposed above the water's surface.

Maintenance has included the placement of additional sand, as needed. Nonetheless, these conditions have led the WDNR to raise questions that affect not only this project, but that will most likely be relevant in evaluating the design or implementability of future ISCs. These issues include the following (Janisch, 2002):

- In light of these initial observations (which to date affect only relatively small areas), what are the implications for long-term stability and effectiveness?
- Will water levels or ice action cause additional damage or worsen the existing defects?
- What is an appropriate degree of monitoring and maintenance over the long term?

While the RP has met the state's requirements to date, the WDNR does not currently have a mechanism in place for maintenance over the longer term. With this experience, department staff now recognize that some kind of extended monitoring or financial assurance may be needed as conditions of future orders.

For caps over contaminated soil and waste material, the WDNR has used both the NR 700 and NR 500 series of regulations as appropriate. Some specific examples include the following:

- When direct contact is the exposure pathway, the remedy selection process within NR 726 has resulted in the use of soil caps consisting of 1 to 2 feet of clean soil. (Note that a direct contact pathway for unsaturated soil would be analogous to an aquatic uptake pathway for sediment. The remedial objective of isolating the material is met by providing a layer of material of designated thickness.)

- When waste material has been excavated and relocated or consolidated, a cover designed according to the NR 500 rules has been required. Depending on the nature of the material, it may also be underlain by a liner designed according to NR 500 requirements. (In at least one innovative application, the NR 500 liner design was modified to add a layer or chemically reactive material suitable for neutralizing an acidic leachate.)

- When deed restrictions are needed on the capped property, NR 726 is used.

When long-term maintenance or monitoring is necessary, NR 700 has been invoked. The cases noted have generally involved larger, financially stable RPs, and financial responsibility has not been questioned. The issue of using NR 500 financial assurance requirements as a relevant and appropriate requirement for an NR 700 maintenance activity has apparently not yet been explored. In this regard, it is interesting to note that as early as 1999, a review of the Sheboygan remedy completed on behalf of the Lake Michigan Federation pointed to the need for an escrow account to cover the costs of long-term impacts when impacted sediments are left in place (BT2, 1999).

6 COST ESTIMATES

The cost of capping projects will be largely dependent on the thickness of the cap, cost of capping materials, and associated transportation and placement costs. However, monitoring costs can be significant when long-term needs are considered. Some example projects are discussed below.

The Simpson Cap was part of a 1988 cleanup of the St. Paul Waterway (part of the Commencement Bay Nearshore/Tideflats Superfund site in Tacoma, Washington). The PRPs dredged clean sediment from the nearby Puyallup River to cap dioxin-contaminated sediments with a 17-acre, 4- to 20-foot-thick cap, at a cost of $5 million, or about $290,000 per acre. The cap had two purposes: to isolate the contaminated sediment and to raise the bottom elevation to create a new intertidal habitat. Estimated long-term monitoring costs were $3 million for the first 10 years of monitoring.

The East Operable Unit of the Eagle Harbor Superfund Site at Bainbridge Island, Washington was constructed in 1994. At this site, the EPA and USACE placed a 50-acre, 3-foot-thick cap over PAH-contaminated sediments. Construction costs were reduced by using clean dredged materials from routine maintenance dredging of the Snohomish River for the cap. The construction cost for this project was $2 million and monitoring costs are approximately $125,000 per year.

The Soda Lake cap was part of a technical feasibility analysis for capping of RCRA refinery residuals at a settling pond located near Casper, Wyoming. Sand was mined on site at a cost of ca. $6.50 per ton, and then placed over a 5.7-acre site to a construction depth of 3 feet, with a 20:1 side slope yielding a total footprint of 7 acres. The base sediments were highly unconsolidated, and thus capping over the main body of the site occurred in 1.5- to 3-inch lifts to allow for slow consolidation and dissipation of accumulated pore pressures to prevent load failure. The cost for construction was approximately $600,000, with an approximate monitoring cost of $250,000 for placement and post-placement monitoring.

Ward Cover near Ketchikan, Alaska was capped as part of a CERCLA action in 2000–2001. Contaminants at Ward Cove were byproducts of the paper waste product that was released during wastewater discharge. The EPA wanted to evaluate a thin-layer capping (6 inches) alternative as a method for enhancing natural recovery and as a habitat improvement action. The underlying material was very soft, unconsolidated sediment with low *in-situ* shear strength and high water content. Placement was with an 8.5-cubic-yard (cy) bucket that was welded to hold an exact amount of material that was equivalent to a 6-inch placement over the 300-square-foot arc across which the bucket was swung. The material was released below the water surface within 10 to 20 feet of the bottom. Sediment grain size for the cap was a fine to medium sand that was less than 5 percent non-plastic silt. The contract was written so that the contractor was paid by the amount of material placed. Gravity probes were used to confirm that the project was successful; a final cap thickness of 6 to 9 inches was achieved. While the cost estimate ranged from

$3.4 to $5.5 million, the actual capping cost was $3.0 million. Post-cap monitoring was not required in this program.

7 CONCLUSIONS

The following conclusions are made regarding regulatory and institutional considerations for selecting and designing subaqueous ISC as a remedy component for the Lower Fox River:

- ISC is a technically feasible remedy approach for the Lower Fox River. However, there are several technical and institutional constraints on the application of capping at this site. Considering these constraints, capping could be a component of a remedy, but could not be the sole remedy for any OU. A combination of some capping and removal is likely the most efficient remedy.

- Technical, regulatory, and institutional issues would need to be appropriately considered in identifying potential areas for capping. Potential areas for capping should be selected based on the following:

  - The overall remedy must manage all sediments within the 1 ppm contour, and should achieve a sediment-weighted average concentration of 250 ppb. No capping would occur in designated navigation channels, with an appropriate setback in areas which may require dredging in the future.

  - No capping within authorized navigation channels (with an appropriate buffer).

  - No capping would occur in areas of infrastructure such as pipelines, utility easements, bridge piers, etc. (with appropriate buffer).

  - No capping would occur in areas with PCB concentrations exceeding TSCA levels.

  - No capping would occur in shallow-water areas (bottom elevations which would result in a cap surface at elevation greater than -3 feet chart datum for OUs 1 and 3 and -4 feet chart datum for OU 4) because of habitat and ice scour considerations without prior deepening to allow for cap placement.

- The composition and thickness of the cap components comprise the cap design. A detailed design effort for any selected capping remedy should address all pertinent design considerations.

- The cap will be designed to provide physical isolation of the PCB-contaminated sediments from benthic organisms.

- The cap will be physically stable from scour by currents, flood flow, and ice scour. The 100-year flood event will be considered in these evaluations.

- The cap will provide isolation of the PCB-contaminated sediments in perpetuity from flux or resuspension into the overlying surface waters.

- The performance criteria for chemical isolation will be a limit of 250 ppb of PCBs in the cap sediment (dry-weight basis) in the biologically active zone, defined as the upper 10 cm of the isolation layer of the cap. This standard would apply as a construction standard to ensure the cap is initially placed as a clean layer, and would also apply as a long-term limit with respect to chemical isolation.

- The cap design will consider operational factors such as the potential for cap and sediment mixing during cap placement and variability in the placed cap thickness.

- The cap design will incorporate an appropriate factor of safety to account for uncertainty in site conditions, sediment properties, and migration processes.

- Institutional/regulatory constraints associated with capping, such as capping TSCA materials, lake bed grants, riparian owner issues, deed restrictions, fiduciary responsibility, and long-term liability should be fully considered in selecting potential areas for capping and in design of the caps for specific areas.

- Application of these considerations is occurring as part of the detailed design component of the Lower Fox River project.

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